INDIAN RAILWAYS ORGANISATION FOR ALTERNATE FUELS

MINISTRY OF RAILWAYS

GOVERNMENT OF INDIA

NEW DELHI

LIQUEFIED NATURAL GAS (LNG)

A CONCEPT PAPER
ON
ALTERNATE FUELS FOR INDIAN RAILWAYS

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INDIAN RAILWAYS ORGANISATION FOR ALTERNATE FUELS
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LIQUEFIED NATURAL GAS – ROADMAP FOR INDIAN RAILWAYS

Natural gas is finding its place at the centre of the energy discussion. The recent emergence of substantial new supplies of natural gas in the World, primarily as a result of the remarkable speed and scale of shale gas development, has heightened awareness of natural gas as a key component of energy supply and has lowered prices well below historical and recent expectations. Increasing gas finds, development of technology to tap shale gas reserves and liquefaction and transportation infrastructure has given a new hope to the mankind that energy intensity of our lifestyle does not necessarily have to be at the cost of unacceptable Green House Gas (GHG) emissions. This concept paper seeks to initiate discussion about the future of natural gas, particularly in a carbon constrained Indian economy with the Indian Railways perspective.

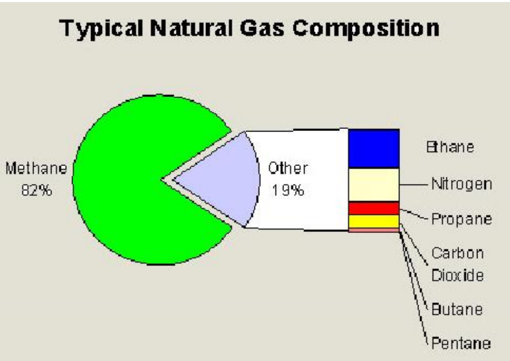
Liquefied Natural Gas (LNG) is a low Carbon, fuel that is perfect for heavy duty engines involved in long haul freight transport across long distances. Liquefied Natural Gas is Compressed Natural Gas in a frozen state allowing much greater fuel storage aboard heavy duty freight vehicles allowing comparable refueling with diesel.

A. WHAT IS LIQUEFIED NATURAL GAS (LNG)

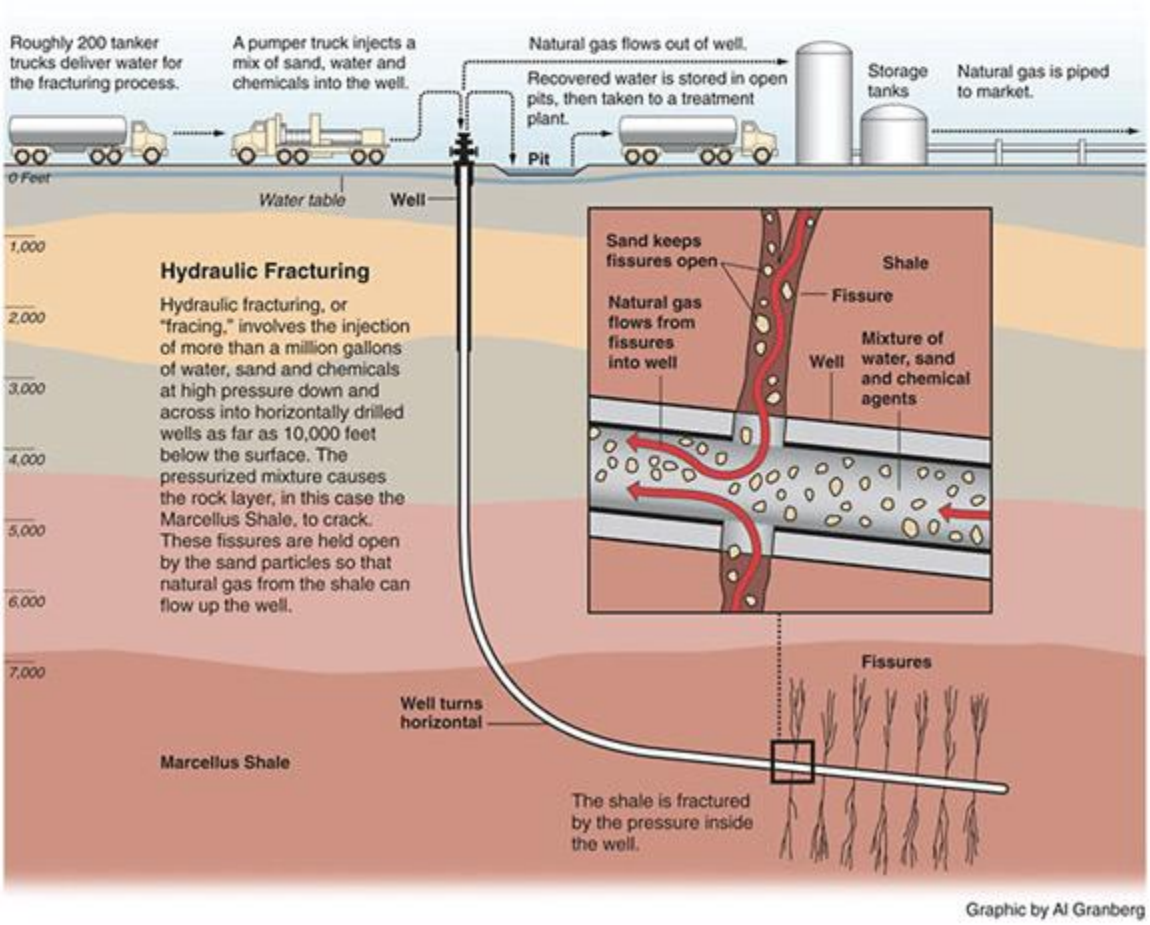
Natural gas is now a vital component of the world's supply of energy. It is one of the cleanest, safest, and most useful of all energy sources. Natural gas is a combustible mixture of hydrocarbon gases. It is colorless, shapeless, and odorless in its pure form and when burned it gives off a great deal of energy and few emissions. Unlike other fossil fuels, natural gas is clean burning and emits lower levels of potentially harmful byproducts into the air. Natural gas is composed primarily of methane, but may also contain ethane, propane and heavier hydrocarbons. Small quantities of nitrogen, oxygen, carbon dioxide, sulfur compounds, and water may also be found in natural gas.

Composition of Natural Gas

Component	Chemical formulae	Percentage
Methane	CH_4	70-90%
Ethane	C_2H_5	0-20%
Propane	C_3H_8	
butane	C_4H_{10}	
Carbon di oxide	CO_2	0-8%
Nitrogen	N_2	0-5%
Hydrogen sulphide	H_2S	0-5%



Shale gas refers to natural gas that is trapped within shale formations. Shales are fine-grained sedimentary rocks that can be rich sources of petroleum and natural gas. Over the past decade, the combination of horizontal drilling and hydraulic fracturing has allowed access to large volumes of shale gas that were previously uneconomical to produce. The production of natural gas from shale formations has rejuvenated the natural gas industry.



Cooling natural gas to about -260°F at normal pressure results in the condensation of the gas into liquid form, known as Liquefied Natural Gas (LNG). LNG can be very useful, particularly for the transportation of natural gas, since LNG takes up about one six hundredth the volume of gaseous natural gas. While LNG is reasonably costly to produce, advances in technology are reducing the costs associated with the liquefaction and regasification of LNG. Because it is easy to transport, LNG can serve to make economical those stranded natural gas deposits for which the construction of pipelines is uneconomical.

The liquefaction process requires the removal of some of the non-methane components such as water and carbon dioxide from the produced natural gas to prevent them from forming solids when the gas is cooled to about LNG temperature (-161C). As a result, LNG is typically made up mostly of methane as shown in Figure 5. (Source: *Liquid Methane Fuel Characterization and Safety Assessment Report. Cryogenic Fuels Inc. Report No. CFI-1600, Dec. 1991)*

A.1 Physical and Chemical Properties:

Chemical Composition	**CH_4 and minor presence of ethane/propane and Nitrogen**
Gross Calorific Value	**51500 Btu/kg or 12978 Kcal/kg approx.**
Molecular Weight	16.042 approx.
Melting Point @ 1 atm	-182.2°C (-296 °F)
Boiling Point @ 1 atm	-161°C (Diesel: 180–360°C)
Auto Ignition Temperature	537.20 °C
Expansion Ratio for liquid at boiling point to gas at 60°F (15.6°C)	1 to 627
Liquid Density at boiling point	426 kg/m^3 (Diesel: 832 kg/m^3)
Appearance, Odor and State	Colorless and odorless cryogenic liquid

B. WHY LNG

B.1 Abundance

Liquefied Natural Gas (LNG) is the fuel of the future. Natural gas is a fossil fuel, just like petroleum and coal, the other two major sources of energy of the world today. Coal, petroleum and gas contribute almost equally to more than 90% energy needs of the world. Coal being a big pollutant of environment, has always been a less preferred choice of energy providers. Proven petroleum reserves of the world are expected to feed the present consumption of mankind for only about next 40-45 years. With the extraction of shale gas getting more economical with advent of new technology, the future prospects of this fuel is very rosy. The present reserves of natural gas are of more than 100 years and are expected to further increase with new finds. Thus, world-wide efforts are on to substitute petroleum and other fuels with gas based applications and in the times to come the major consumption of diesel/petrol of today will get substituted by gas

B.2 Environmental Friendly Fuel

Natural gas is the cleanest of all the fossil fuels; the emission of harmful flue gases like SO2, NO2, CO etc. gets substantially reduced using LNG. The emission factor of LNG is only 56100 Kg/TJ as compared to emission factor of 74100 kg/TJ of diesel. There is carbon emission reduction of approx. 0.7 ton per 1000 liters of diesel used by replacing it with LNG.

Natural gas is the cleanest of all the fossil fuels, Composed primarily of methane, the main products of the combustion of natural gas are carbon dioxide and water vapor. Coal and oil are composed of much more complex molecules, with a higher carbon ratio and higher nitrogen and sulfur contents. This means that when combusted, coal and oil release higher levels of harmful emissions, including a higher ratio of carbon emissions, nitrogen oxides (NOx), and sulfur dioxide (SO2). Coal and fuel oil also release ash particles into the environment, substances that do not burn but instead are carried into the atmosphere and contribute to pollution. The combustion of natural gas, on the other hand, releases very small amounts of sulfur dioxide and nitrogen oxides, virtually no ash or particulate matter, and lower levels of carbon dioxide, carbon monoxide, and other reactive hydrocarbons.

Fossil Fuel Emission Levels
- Pounds per Billion Btu of Energy Input

Pollutant	Natural Gas	Oil	Coal
Carbon Dioxide	117,000	164,000	208,000
Carbon Monoxide	40	33	208
Nitrogen Oxides	92	448	457
Sulfur Dioxide	1	1,122	2,591
Particulates	7	84	2,744
Mercury	0.000	0.007	0.016

Source: EIA - Natural Gas Issues and Trends 1998

B.3 Safer than Diesel and CNG

Natural gas has auto ignition temperature of LNG is 537°C as compared to around 210°C of diesel and a flammability rating of approximately 5 to 15% (safest range among all fossil fuels) gas in air. This reduces the risk of fire if and when a leak happens. Natural gas is also lighter than air and will simply dissipate into the atmosphere in the case of leaks. Meanwhile, gasoline or diesel will pool in the ground when there is a leak which results in a very dangerous fire hazard. Lastly, natural gas is a non-toxic fuel that does not pose any danger of contamination to ground water. A quick comparison is given below:

Property	**LNG**	**High Speed Diesel**
Density	426 kg/m^3	832 kg/m^3
Storage Pressure	Atmospheric at -161^{0}C	Atmospheric
Auto-ignition Temp	537^{0}C as gas Non-inflammable as liquid	210^{0}C
Flammability Rating	5% - 15%	0.6% - 7.5%

B.5 Efficient Fuel

Natural gas is mainly methane (CH4), which burns to produce heat. The calorific value by mass (per kg) of natural gas is better than most of the conventional fuels being used, such as petrol, diesel, LPG, kerosene, furnace oil etc.

$$CH_4 + 2O_2 \rightarrow CO_2 + 2\ H_2O$$

High Speed Diesel, on the other hand is a mixture of hydrocarbons ranging from C10H20 to C15H28 and "averages" to C12H23. The chemical equation for the complete combustion of Diesel fuel would then be:

$$4C_{12}H_{23} + 71O_2 \rightarrow 48CO_2 + 46H_2O$$

LNG has more calorific value (12950 Kcal/Kg) as compared to Diesel (10900 Kcal/Kg).

B.6 No Pilferage

As the LNG is cryogenic liquid having temperature of minus 162 °C, it is theft-proof.

C. GLOBAL SCENARIO

C.1 Production and Consumption Trends

Driven by surging natural gas consumption in Asia and the United States, global use of this form of fossil fuel rebounded 7.4 percent from its 2009 slump to hit a record 111.9 trillion cubic feet in 2010 (*Ref: Vital Signs Online report from the World Watch Institute*). This increase puts natural gas's share of total energy consumption at 23.8 percent, a reflection of new pipelines and natural gas terminals in many countries.

The world's largest incremental increase in natural gas use occurred in the United States, where low prices triggered a 1.3 trillion-cubic-feet increase to 24.1 trillion cubic feet, just over one-fifth of global natural gas consumption. 30% of its domestic gas supplies are currently met at present though shale gas. *(http://economictimes.indiatimes.com/news/news-by-industry/energy/oil-gas/shale-oil-and-gas-exploration-policy-is-ready-petroleum-secretary/articleshow/22141871.cms).*

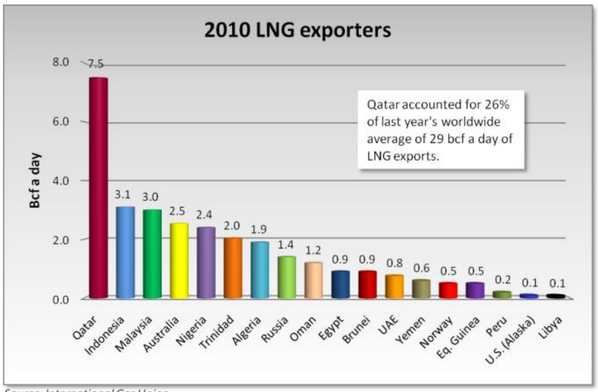
The Asia Pacific region experienced the strongest growth as a share of 2009 consumption levels, with China, India, South Korea, and Taiwan all experiencing demand growth of over 20 percent. China, which surpassed Japan in 2009 to become Asia's largest natural gas consumer, by and large led the region's growth spurt by consuming 3.9 trillion cubic feet, or 3.4 percent of world usage.

The former Soviet Union, which experienced the largest regional decline in natural gas consumption in 2009, saw its demand bounce back by 6.8 percent in 2010. Russia, the world's second largest natural gas consumer, single-handedly accounted for 70 percent of regional growth. In the European Union, natural gas consumption increased by 7.4 percent; The Middle East saw a 6.2 percent rise in natural gas demand.

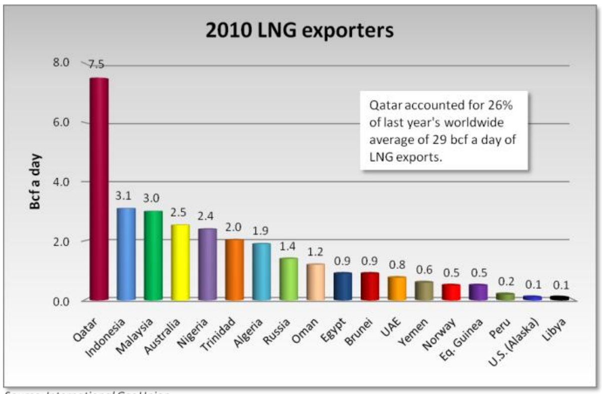
Natural gas producers have responded to this revived demand with a 7.3 percent boost in production. The United States maintained its position as the leading source of natural gas, accounting for just under one-fifth of the world's total production in 2010. In Russia, which holds nearly a quarter of the world's proved natural gas reserves, production jumped 11.6 percent. In the Middle East, growth in production of natural gas far outstripped that of consumption, rising by a full 13.2 percent. In the year 2011, Qatar and Iran alone accounted for 29.4 percent of global proven reserves.

Reenergized global gas demand drove average prices up from their 2009 lows in nearly all markets. According to one index, the U.S. saw a 13 percent price increase over 2009 levels. Prices remained the highest in Asia, where consumption increased most rapidly between 2009 and 2010. The European Union, where prices fell 6 percent, proved to be the exception to this trend, thanks to an excess of liquid natural gas originally intended for U.S. markets.

A large part of the export of natural gas takes in the form of Liquid through the cryogenic route. Major exporters and importers are as follows *(Ref: http://www.arcticgas.gov):*



Source: International Gas Union



Source: International Gas Union

The share of global natural gas trade represented by liquefied natural gas (LNG) surpassed 30 percent in 2010 for the first time on record. Major consumers of natural gas (including LNG) are as follows:

Country Name	Natural gas - consumption (billion cubic meters)	Year of Estimate
United States	683.30	2010
Russia	414.10	2010
Iran	137.50	2012
China	129.00	2011
Japan	100.30	2010
Germany	99.50	2010
United Kingdom	94.28	2010
Saudi Arabia	83.94	2010
Canada	82.48	2010
Italy	77.80	2011
India	64.95	2010
Mexico	62.42	2010
United Arab Emirates	59.08	2009
Netherlands	53.19	2010

C.1 LNG in Non-Rail Transport Applications:

LNG has been deployed on over 1000 heavy duty trucks (400 – 500 hp) worldwide. Wartsilla and MAN have been manufacturing LNG marine engines for many years. CATERPILLAR is developing LNG engines in 2000 hp range. MTU has signed an agreement with Westport to develop high horsepower LNG engine.

Shell, a major player, has made available liquefied natural gas (LNG) for heavy-duty fleet customers beginning in 2012 at select Shell Flying J truck stops in Alberta, Canada. Shell also signed agreements with a number of partners to supply LNG for marine engines along the US Gulf Coast and to support the use of LNG fuels in rail transport and in mining. With the abundance and low cost of natural gas, Shell is also actively developing new business opportunities with OEMs to substitute LNG for diesel and propane in a number of industrial sectors such as marine, on-road trucking, rail, mining and oil and gas drilling applications.

C.2 LNG in Rail Traction:

C.2.1 Early Usage

Among the earliest experiments in use of LNG on diesel locomotives, the BNSF (Burlington Northern) in USA ran its first ECI technology enabled SD40-2 locomotives to haul coal between Wyoming and Wisconsin from 1991 to 1996, using LNG fuel. Early experiments were discontinued due to rise in prices of natural gas.

C.2.2 USA

The Pacific Harbor Line, Inc. (PHL) operating within and surrounding the ports of Long Beach and Los Angeles, ran a programme in the year 2009 of converting shunting locomotives to LNG (with spark ignition) to demonstrate the technology's suitability and emissions reduction characteristics. Despite its apparent higher rate of fuel consumption, the LNG locomotive cost approximately 23% less to fuel on an energy-equivalent basis compared to diesel fuel. The LNG switcher locomotive established estimated 92% reduction in less oxides of nitrogen (NOx) and 76% less particulate matter (PM) compared to the baseline (uncontrolled) diesel locomotives.
(Ref: Demonstration of a Liquid Natural Gas Fueled Switcher Locomotive at Pacific Harbor Line, Inc. Report by Patrick Couch Jon Leonard Helena Chiang, April 2010.)

EMD and Westport are jointly working on developing the first LNG loco in the Year 2014.

C.2.3 Canada

CN – the Canadian National Railway Company, in the most recent developments (September 2011) converted two EMD locomotives to LNG and deployed them on revenue runs between Edmonton and the tar sands town of Fort McMurray with locomotives converted to LNG-diesel dual fuel operation. The Alberta train uses hydraulic direct injection technology from Energy Conversions, Inc. of Tacoma, Wash. This represents the latest technologies available today.

The single LNG tender supports twin EMD SD40-2 locomotives with 16-645E3 engines, modified to run on an LNG-diesel mix using an ECI kit and key software. The fuel is vaporized on the tender and carried cross the couplers as a warmed gas.

ECI's hydraulic direct injection system is designed to displace as much as 94% to 96% of the diesel fuel at cruise. Overall in-service displacement is likely to be 75% to 80%. The engine starts on diesel, and can run on pure diesel if need be.

C.2.4 Russia

Russian Railways Company developed the world's first gas turbine locomotive in the year 2008. The 8.3 MW GT1-001 Locomotive goes 750km on one fuelling with a 10,000 tonnes trailing load at 100kmph. Fuel consumption is 30% less than fuel consumption of a diesel locomotive. In addition the LNG used in this locomotive itself is cheaper than high speed diesel. The main advantage of GTEL is a possibility to reach high power with rather small size and weight. *(http://ruvr.ru/main.php?lng=eng&q=37570&cid=172&p=29.12.2008)*

C.2.5 Australia

A collaborative programme of the Australian Railroad Industry plans to launch a joint research and development budgeted at $37 million over five years. This program would focus on developing solutions to utilise natural gas as a primary alternative fuel in high powered and well-utilised locomotives. Australia has a very large supply of natural gas. This would reduce emissions, increase energy security and assist in developing a globally unique centre of excellence. The industry is ready and willing to make substantial investments towards this goal. *(Ref: Australian Railway Association, Nov. 2010)*

D. SPECIAL FEATURES OF LNG TRADE

Being capital intensive, LNG is mostly traded as dedicated chains, where production, liquefaction, storage, regassification, road transport and user-end storage is established in advance. Any LNG Project, thus begins only when the complete chain is tied up. LNG sale and purchase contracts are long term (typically 20 years or longer). Often the dispatching and receiving terminals are owned and operated by consortiums. Pipelines typically cater to large consumers – Power Plants, Fertilizer Units or City Gas. LNG on the other hand can also cater to small off takes – engineering industry, workshops, road vehicles and locomotives.

D.1 LNG Transportation Logistics:

LNG is shipped around the world in specially constructed dedicated seagoing vessels, which are un-loaded at specially designed dedicated ports having LNG bulk storage and re-gas facilities, and these LNG unloading points are connected to the consumer destination locations through a gas pipeline network or in cryogenic storage road tanker lorries.

Qatar, Malaysia, Indonesia, Algeria, Nigeria, Australia, Trinidad and Tobago and Egypt are the major LNG producing countries. Major international-oil-companies (IOCs), such as ExxonMobil, Royal Dutch, Shell, VP, VG Group and Chevron and national-oil-companies (NOCs), such as Pertamina and Petronas are active players in this field.

Receiving terminals exist in about 18 countries, including India, Japan, Korea, Taiwan, China, Belgium, Spain, Italy, France, The UK, The US, Chile and the Dominican Republic, among others. Plans exist for Argentina, Brazil, Uruguay, Canada, Greece, Ukraine and others to also construct new receiving and gasification terminals. As the demand for gas increases in the world, more projects for liquefying and regassifying natural gas are being set-up.

The commercial development of an LNG liquefaction plant is based on a value chain, which involves LNG distributers first confirming sales from the downstream buyers and then signing up 20-25 years contracts, with strict terms and structures for gas pricing with the LNG producers. Only when the volumes (according to the assured demands from customers) are confirmed, the development of the green-field project is deemed to be economically feasible, and the sponsors invest money in the development and operation of a LNG project.

D.2 LNG Pricing and Purchase Agreements

The selling price of gas in a particular market is linked to the prices at multiple gas supply points. For example, India's new pricing formula is based on a 12-month average of gas prices in other regional markets, including U.S. Henry Hub, the National Balancing Point in the United Kingdom, and a netback price at the source of LNG supply for Japan. It also incorporates the netback price of Indian LNG-contract imports at the wellhead of the exporting countries.

There are complex, but universally accepted Price Variation Clauses, which govern the long term contracts for gas supply, both piped and liquefied. Spot purchase of gas is possible, but not preferred for LNG.

The trade of LNG is completed by signing a sale-and-purchase-agreement (SPA) between a supplier and receiving terminal, and by signing a Gas-Sale-Agreement (GAS) between a receiving terminal and end-users. Most of the contract terms used to be destination or ex-ship, holding the seller responsible for the transport of the gas. With low shipbuilding costs, and the buyers preferring to ensure reliable and stable supply, however, contract with the term of free-on–board (FOB) increased. Under such term, the buyer, who often owns a vessel or signs a long-term charter agreement with independent carriers, is responsible for the transport.

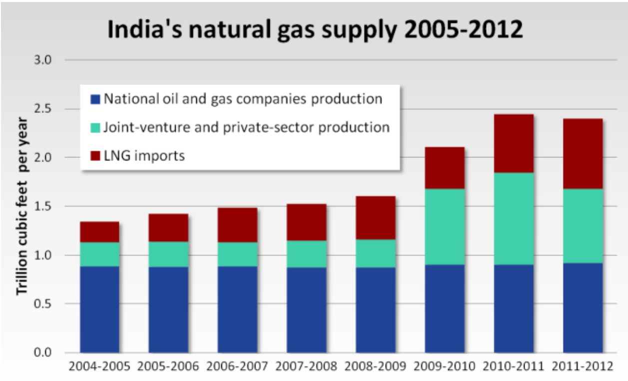
LNG purchasing agreements used to be for a long term with relatively little flexibility both in price and volume. If the annual contract quantity is confirmed, the buyer is obliged to take and pay for the product or pay for it even if not taken, in what is referred to as the obligation of take-or-pay (TOP) contract.

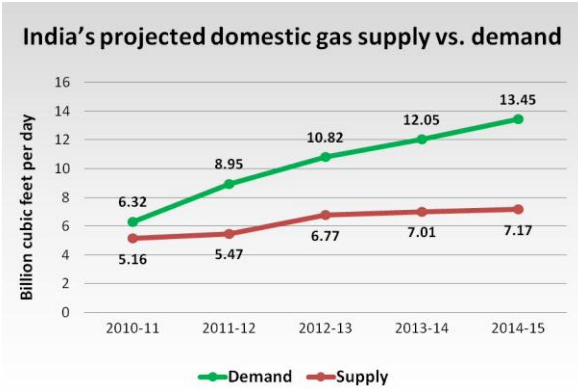
Until 2003, LNG prices have closely followed oil prices. Since then, LNG prices in Europe and Japan have been lower than oil prices, although the link between LNG and oil is still strong. In contrast, prices in the US and the UK have recently skyrocketed, then fallen as a result of changes in supply and storage. Shale gas discoveries have brought a new element in the price calculations.

E. INDIAN SCENARIO

E.1 Production, Consumption and Imports

Production of natural gas in India has lagged behind the requirement and the gap is steadily increasing. India is thus a net importer of natural gas, even though significant finds have been achieved in recent years. The import of LNG is mainly for meeting the shortfall for the gas users who are connected to pipelines, hence most of it is regassified.





(Charts ref: http://www.arcticgas.gov/china-and-india-hope-higher-prices-will-spur-gas-production)

India's natural gas production has steadily declined over the last two years to 111mmscmd in FY 13 from 143mmscmd in FY 11 primarily due to fall in production of KG-D6 block from 56 mmscmd in FY 11 to 26mmscmd in FY 2013. Factoring in certain production from future discoveries, ICRA estimates the domestic production could increase to about 200mmscmd by FY 25 notwithstanding the fall in the production from the existing fields. *(Ref: http://timesofindia.indiatimes.com/business/india-business/Domestic-natural-gas-production-to-increase-around-183mmscmd-by-FY-20-CRA/articleshow/21557451.cms)*

With the recently announced gas pricing formula to come into effect from 1st April, 2014, gas production in India is expected to grow by 67% by 2016-17 *(http://articles.economictimes.indiatimes.com/2013-07-20/news/40682187_1_mmscmd-gas-output-gas-production).*

Government of India also has a long term plan for exploration and extraction of shale gas. This has been facilitated by the government's policy to treat shale gas at par with the production of conventional oil and gas for all purposes of exploration licence and mining lease. A new shale gas policy is likely to be announced in September 2013.
(Ref: http://www.indianexpress.com/news/oil-min-plans-sops-to-boost-shale-gas-production/1154066/)
Quite clearly there will be abundant import of LNG in the coming years. It is LNG that is required for locomotives.

E.2 LNG Imports

As India does not have any pipeline connection, all the gas currently imported is LNG. Current operational LNG import capacity is 13.5 mtpa (18 bcm). India joined the global LNG market in March 2004 when the Dahej LNG terminal went into operation. Petronet LNG Limited (PLL), a joint venture promoted by GAIL, IOCL, Bahrat Petroleum (BPCL), GDF Suez, the Asian Development Bank (ADB) and ONGC was formed to import LNG in order to meet the growing gas demand. IEA's forecasts on demand and domestic production imply a supply gap of 18 bcm by 2015, increasing to 28 bcm by 2020 and 52 bcm by 2030. In any case, LNG seems set to remain the first source of imports for India for at least the five years to come. *(Ref: International Energy Agency Report, 2010).*

E.3 LNG Pricing in India

LNG prices negotiated in India at present can be broadly classified under three categories — long-term contracted LNG, medium-term and spot LNG.

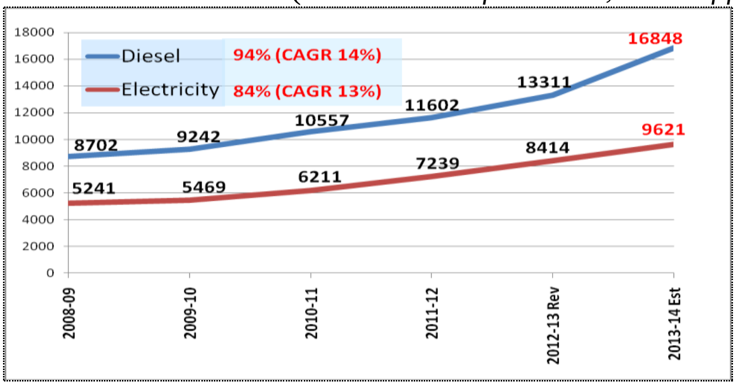
Long-term contract: PLL has signed long term LNG supply contracts with Qatar and Australia. Long-term LNG prices are generally linked to JCC crude oil under an agreed formula, and commercial negotiations determined the linkage percentage. The Australia contract is understood to be contracted at a higher JCC linkage than the Qatar contract. Prevailing prevalent ex-terminal LNG prices are about USD 10-11 per mmbtu (through Qatar contract). GAIL has recently signed a term contract linked to Henry Hub.

Medium-term contract: For medium term contract it was reported that GAIL has signed a two year contract with GDF Suez to import 0.8 million tonnes of LNG7.

Spot LNG: Spot LNG prices are determined through commercial negotiations and have been in the range of USD 13–16 mmbtu in recent months.
(http://www.kpmg.com/in/en/issuesandinsights/articlespublications/kbuzz/pages/enr-august2012.aspx)

F. ECONOMICS OF LNG IN DIESEL TRACTION

Nearly a quarter of Ordinary Working Expenses of Indian Railways go towards energy (Diesel and Electricity). Energy prices rising across the board – Both Diesel and Electricity. The trend is indicated in the chart below (Ref: *Demands for Grants, Part I of five years*):



There is, therefore, an urgent need to address the rapidly rising cost of traction fuel.

LNG offers a state of the art, yet financially viable solution as far as diesel traction is concerned. LNG not only has higher calorific value per unit weight compared to high speed diesel, it is also cheaper per unit energy. Cost economics of LNG vis-à-vis HSD is given below:

1	Price of Imported LNG (US$ 14-15 per mmBTU)	Rs 52.00	per kg
2	Price of High Speed Diesel	Rs. 61.00	per litre
3	Density of HSD	835	Kg/m3
4	Price of Diesel by weight	Rs.73.00	Per kg
5	Heating value of LNG	51.6	MJ/kg
6	Heating Value of HSD	43.2	MJ/kg
7	Price of LNG energy	Rs. 1.00	per MJ
8	Price of HSD energy	Rs. 1.69	Per MJ
9	Benefit of Using LNG	Cheaper by 42%	Per unit energy

F.1 How does the investment in LNG technology pay

- A Diesel Loco, on an average, consumes Diesel worth Rs. 4 Crores per annum
- LNG retrofit likely to cost Rs. 5.5 Crores per loco
- LNG saves 42% on fuel costs, i.e. 1.60 Crores p.a.
- Payback period is less than 5 years.
- Strong case for emulating North America (USA and Canada)

F.2 Do We Have Enough Natural Gas and LNG

In order to support the development of the Indian economy with gas-fired power generation facilities and with methane feedstock for the petrochemical industry, the Indian Government is forecasting the domestic demand for natural gas to more than triple from actual 13.5 million tonnes in 2012 to estimated 48 million tonnes in 2017.

India has 1241 billion cubic meters of Conventional Natural Gas and 7463 billion cubic meters of Shale Gas. At present consumption rate of 291.6 mcm per day these reserves will last 80 years. Government policy framework on shale gas exploration expected by end of 2013. Commercial production of shale gas is expected to begin by Year 2017. Natural gas including shale gas is emerging as fuel of future with projected world reserves of more than 200 years.

With the ongoing expansions of the existing LNG Terminals located on Dahej and Hazira operated by Petronet LNG and Shell, the new projects of LNG Terminal planned by GSPC, and Indian Oil in Mundra, Okha, Pipavav and Ennore should help to triple the volume of liquid natural gas imported in India in 2017.
(http://www.2b1stconsulting.com/india-to-triple-lng-import-terminal-capacities-by-2017/)

Several other terminals are also being planned by various players at Dhamra, Kakinada, Gangavaram, Kochi, Mangalore and Dighi. Such a vast network of LNG receiving terminals will aid and ensure supply of LNG to users all over the hinterland.

Current consumers of Natural Gas are given in the following tables *(Ref: Report of the Working Group on Petroleum and Natural Gas for the 12th Plan, MOPNG, Nov 2011).*

Table 11.3 Consumption of Natural Gas by Sector, June 2011

Sector	Supply (MMSCMD)	% of total Supply
Power Sector	61.4	37.0
Fertilisers	37.7	22.7
CGD (Domestic + CNG)	7.9	4.8
Court Mandated Customer	1.0	0.7
Shrinkage for Liquid extraction -LPG etc.	7.2	4.3
CGD Commercial & Industrial	6.0	3.7
Refineries	19.8	11.9
Petrochemicals	5.7	3.4
Sponge Iron	7.0	4.2
Small consumer having allocation <50,000	5.8	3.5
Others	4.5	2.7
Internal Consumption-Pipeline system	2.1	1.2
Total Supply	**166.2**	**100**

Table 11.4 Sector wise consumption of R-LNG

Sector	RLNG Consumption including Spot (MMSCMD)	%
Power	5.0	11
Fertilizer	8.2	18
CGD + Court Mandated Consumers	6.9	15
Refineries	16.7	36
Petrochemicals	1.3	3
Sponge Iron	4.1	9
Consumers having allocation<50,000 SCMD	0.9	2
Others	3.1	7
Grand Total	**46.2**	100

RLNG – Re-gassified Liquid Natural Gas)

As can be seen from above, Indian Railways have been left far behind other sectors in use of natural gas.

- Indian Railways presently consume about 2.5 billion liters of diesel annually.
- Equivalent natural gas consumption will be about 1.8 million tons at 95% substitution.
- Current consumption of natural gas in India: 13.5 million tons
- Estimated imports: 48 million tonnes by 2016-17 and 60 million tonnes by 2020.
- **Even with a complete changeover of all locomotives from HSD to LNG, IR will tap into less than 3% of the national gas consumption by 2020.**

G. LNG TECHNOLOGIES FOR LARGE ENGINES:

There are three main approaches to the LNG usage on vehicles. In order of increasing complexity and costs these are "Spark Ignition", "Port-Injection Dual Fuel" and "Late Cycle High Pressure Direct Injection". A brief comparison of the three types is given overleaf:

Spark-Ignited (SI)	**Port Injection** **Dual-Fuel (DF)**	**Late Cycle High Pressure Direct Injection**
How it Works ▪ Involves a complete change of engine ▪ Gas and air pre-mixed at low pressure ▪ Ignition from spark plug ▪ Similar to DTC Buses ▪ 100% replacement by CNG. **Limitations** ▪ Low Efficiencies ▪ De-rating of engine by 30% ▪ Not preferred for heavy duty loco application especially for IR duty cycle	**How it Works** ▪ Minor changes in engine ▪ Gas and air pre-mixed at low pressure ▪ Diesel injection for ignition ▪ Can revert to diesel fuel on Diesel cycle **Limitations** ▪ Lower Efficiencies ▪ Only upto 35-40% displacement of diesel by natural gas with IR duty cycle ▪ Not preferred for heavy duty loco application	**How it Works** ▪ Major engine modifications called for. ▪ High pressure gas injected directly into combustion chamber ▪ Ignition from diesel pilot ▪ Efficiencies similar to diesel ▪ Upto 95% displacement of diesel by natural gas ▪ Preferred solution for heavy duty diesel engines ▪ Most suitable with IR duty cycle **Limitations** ▪ Can't revert to pure diesel easily

H. SPECIAL CASE FOR SPARK-IGNITION (SI) GAS ENGINES

H.1 The Delhi Experiment with Buses and TSRs

Conversion of DTC buses in Delhi, along with Three-wheeler Scooter Rickshaws (TSRs) has been one of the greatest demonstrators and success stories for clean engine technology in India. TSRs were already equipped with SI engines (petrol engines) hence their conversion to CNG was an easy task. Buses, on the other hand, had diesel engines. These engines had to be replaced with Spark Ignition engines, so that they could work with 100% CNG fuel. Other technologies, such as Port Injection or High Pressure direct Injection are more efficient, but require complex engine control and retrofits. Moreover, these technologies still require at least a pilot diesel injection; hence do not offer a complete switchover to CNG. But, the simplicity of SI technology with CNG comes with a 30% power penalty (de-rating of the engine) compared to the diesel engines of similar size. This, however, was not a constraining factor with buses, which operate at much lower loads compared to trucks built on the same platform. This switchover to CNG played a major role in cleaning up the air of Delhi.

H.2 Spark Ignition Engines for Locomotives

The trials of SI-engine shunting locomotives in the Pacific Harbour Line (Ref: Para C.2.2 above) established 23% saving in fuel costs, 92% reduction of nitrogen oxides (NOx) and 76% reduction in particulate matter (PM) compared to the baseline (uncontrolled) diesel locomotives. This trial clearly established that SI-technology is a viable and desirable option for shunting locomotives for major urban centres, such as Delhi and Mumbai. Shunting locomotives in the yards of Delhi and Mumbai, to start with, needs to be retrofitted with SI-engine.

Thousands of SI-gas engines have been built for stationary applications. Santa Fe Railroad Company in USA is operating 1000KW shunting locomotives for several years with Caterpillar G2516 SI-gas engines. Deutsche Bahn (Germany) too is operating shunting locomotives with 472 KW Caterpillar G308 SI engines.

Application of LNG on shunting locomotives in major urban centres must be pursued seriously by IR. Apart from bringing in at least 25-30% saving in fuel costs, it will also eliminate pollution caused by yard-switching operations. Even with reduced power density compared to diesel fuel, use of gas will not impact shunting efficiency. Moreover, since shunting operations are in a geographically confined area, logistics for LNG will be easier than mainline. It will, however, provided the necessary experience and create necessary supply chain for eventual migration to LNG on mainline loco operations.

It is suggested that at least ten LNG powered shunting locomotives each be introduced at the earliest in Delhi and Mumbai yards, followed by proliferation in numbers and in locations. A proposal on these lines will be sent to the Railway Board for inclusion in the RSP for 2014-15.

I. INDIAN RAILWAYS' INITIATIVES IN RAIL TRACTION

I.1 Compressed Natural Gas (CNG)

With the setting up of the Indian Railways Organisation for Alternate Fuels (IROAF) in the Year 2008, IR embarked upon the first project in use of natural gas in diesel traction. Since LNG was not a technological or logistic possibility then, the route adopted was of Compressed Natural Gas (CNG).

One Diesel Power Car (DPC No. 19002 of Shakurbasti Diesel Shed) was converted to CNG-Diesel dual-fuel mode by M/S Cummins India under a contract awarded by Northern Railway. The DPC has been running with limited success since the Year 2005.

The main work of 'conversion of 100 DPCs into dual fuel engine with CNG' was sanctioned in the year 2007-08 under DRF at an anticipated cost of Rs. 75 cr. This project is being executed by IROAF. Under the IROAF project, following 3 contracts have been awarded for CNG conversion of 50 nos. of DPCs (remaining 50 nos. of the sanctioned work will be taken up once the conversion work on the initial 50 DPCs reaches near completion). Details are given below:

i) On 08/04/10, a work to convert 2 nos. of DPCs was awarded to M/S CLH Gaseous Fuel Application Pvt. Ltd, Gurgaon. They have converted 1 DPC No. 11038 of SSB Diesel Shed in July 2012, and it is presently undergoing trials on DEMU services of SSB on Northern Railways. 20% diesel substitution is expected in this conversion. Cost of conversion and retrofit would be Rs. 80 lakhs per DPC.

ii) On 08/07/10, a work to convert 8 nos. of DPCs was awarded to M/S Cummins India Ltd., Pune. Since Northern Railways was not in a position to spare a second DPC (other than DPC No. 11038 given to M/s CLH) for CNG conversion, work on this contract has not started. However, now since it has been decided to execute this work at ICF, Chennai at the DPC production stage, speedy action on the conversion work is expected. At present ICF, Chennai is analyzing the impact of modifications on DPC body shell, after which M/s Cummins will start the work and is expected to complete conversion on each DPC in 4 to 6 weeks' time. 20% diesel substitution is expected in the converted DPCs. Cost of conversion and retrofit would be Rs. 80 lakhs per DPC.

iii) On 11/02/11, a work to convert 40 nos. of DPCs was awarded to M/S Heinzmann, Germany. This work has also got delayed on account of Northern Railways not sparing DPCs for conversion work. At present, DPC No. 11043 of SSB Diesel Shed has been identified for conversion by M/s Heinzmann and has already been handed over to them in the month of July 2013. They are expected to complete the work by Jan 2014. Once the first DPC is cleared by RDSO, further conversion work will be taken up at ICF, Chennai. 65% diesel substitution is expected in this conversion. Cost of conversion and retrofit would be Rs. 1.20 Crores per DPC.

I.1.1 Steps taken/being taken to expedite the implementation process

As stated above, the execution of conversion works has been slow on account of Northern Railways not sparing DPCs. It has now been decided to carry out the CNG conversion work at ICF, Chennai on new DPCs being manufactured, where making available the DPCs for conversion will not be a bottle-neck. The contract of M/S Cummins has already been amended to allow for ICF as a location for conversion work. M/S Cummins has submitted drawings demanded by ICF and ICF is examining the implications of changes on the DPC. Once ICF clears the modifications/drawings, M/s Cummins will supply the CNG cascade and CNG kit at ICF and start the conversion work. Similarly, after the first DPC is modified by M/s Heinzmann and approved by RDSO, next DPCs will be converted by M/s Heinzmann at ICF.

I.2 Liquefied Natural Gas (LNG) – Locomotive Project

Limitations of CNG: CNG must be stored at high pressures (up to 200 bars) in heavy steel cylinders arranged in cascades. This takes a severe penalty on space. CNG cascades are heavy and carry too little fuel per unit weight to be able to provide for high percentage substitution and/or long range between refueling stops. It was possible to work with CNG on DEMUs since they operated in a limited geographical area and could always come back to the home shed for refueling. Even though the initial projects of CNG were conceived for DEMUs, where range of travel was limited, cross country movement of locomotives would require more efficient storage of energy on board. LNG, on the other hand improves energy storage efficiency greatly – an essential requirement for locomotives, which travel long distances between fuelling stops. Upon liquefaction Natural Gas reduces to nearly one-six-hundredth in volume. The storage density of LNG is comparable to high speed diesel with only about 20% space/volume penalty.

Besides, since the engine technology would remain the same whether we used CNG or LNG as the engine deals only with gaseous fuel, the DEMU project would help us establish the optimum technology and the necessary support system, both within Railways and the Industry.

Liquefied Natural Gas (LNG) came into widespread use in India, primarily due to the reason that it provided the only means to import natural gas across seas. Apart from providing a high density energy storage on board, compared to CNG, LNG also offered a cheaper and cleaner substitute for diesel. In fact, LNG can economically replace all the existing fuels like LPG, propane, LDO, furnace oil, naphtha etc. It also replaces CNG without design changes and offers shorter filling time than CNG.

Projects in hand: Indian Railways have taken early steps in the direction of use of LNG, almost in sync with the developed world. Following projects are underway:

- RDSO has developed the technical specification for the prototype LNG-Diesel dual fuel locomotive on the ALCo platform. This is based on the Late cycle high Pressure Direct Injection Technology.
- A Prototype LNG Loco Project was Sanctioned in RSP 2008-09. The tender opened at RDSO over a year ago. Likely to be finalised by Oct 13 for an approximate cost of Rs. 26 Crores when a contract with M/s Westport of USA is expected to be signed.
- Project for retrofitting an additional 20 Locomotives with LNG was sanctioned in the RSP of 2013-14. Specifications are under preparation.

J. INDIAN RAILWAYS' INITIATIVES IN INDUSTRIAL APPLICATION

LNG offers an environment friendly and economical alternative to the industrial fuel used by IR's Production Units and Workshops. Use of natural gas, both as furnace fuel and as an alternative to acetylene has been technologically established in India and abroad.

As a pilot project, a Works Programme Sanction for substituting LNG for LPG was sanctioned for Rail Spring Karkhana, Gwalior in WP for 2012-13 at a cost of Rs. 2.51 Crores. Present consumption of LPG in the factory is about 1000 MT per annum.

Price of LNG (Rs 52/kg) is nearly half of LPG (Rs 100/kg). Payback period is less than a year, apart from environmental benefits! There is a need to replicate this in other Factories and Workshops. It may also become mandated by pollution control norms soon since most units are in cities and towns.

Railway Board has authorised COS/NCR to call for tenders for long term contract for LNG for the RSK, Gwalior.

K. ACTION PLAN AND RECOMMENDATIONS

K.1 LNG for Diesel Traction

K.1.1 Short term – Immediate (6 months – 1 year)

(a) Begin retrofitment of CNG kits on DPCs in ICF against existing contracts of IROAF. ICF, IROAF and RDSO are already on the job.

(b) Set-up CNG filling stations at nominated DEMU sheds, where these DPCs will be homed.

(c) Finalise specifications for the remaining 50 DPCs to be converted to LNG. Original specification provided or CNG only.

(d) Begin work on the prototype LNG locomotive under the RDSO contract.

(e) Finalise specifications for LNG retrofits on a larger fleet of mainline ALCo locomotives.

(f) Issue tenders for retrofits on 20 locomotives – to be done in DMW, Parel or a major POH workshop.

(g) Obtain RSP sanction for conversion of an additional 100 locos in the Budget of 2014-15.

(h) Obtain sanction for conversion of 20 shunting locomotives to LNG with Spark Ignition technology. It is based on simpler technology, similar to that employed in DTC buses, is easy to implement will help clean up the air in cities.

K.1.2 Medium term – (1 year – 3 years)

(a) LNG RCDs (on same business model as Diesel RCDs) to be set up at select locations. First few such RCDs should come in Delhi and Mumbai yards and also at locations, which would also cater to DEMUs.

(b) Develop Specifications for conversion of EMD locomotives.

(c) Retrofit 20 ALCo locomotives against existing sanction.

(d) Retrofit 20 shunting locomotives with SI-technology LNG kits.

(e) Obtain sanction for additional 100 ALCo an 100 EMD Locomotives to be converted to LNG in the year 2015-16 and 2016-17.

(f) Plan regular production for LNG locomotive in DLW/DMW from 2016-17 onwards.

(g) Production programme for the year 2016-17 onwards to include at least 50 factory-fitted EMD locomotives with LNG as fuel.

K.1.2 Long term – (3 years and beyond)

(a) Proliferate LNG RCDs across the country.

(b) Target a population of 1000 LNG locomotives by the Year 2020.

(c) DEMUs with factory-fitted LNG engines to be manufacture in ICF and/or Haldia.

(d) IR should join the consortium of LNG importers of India to get the best prices and assured supplies in the long run.

K.2 LNG as Industrial Fuel

K.2.1 Short term – Immediate (6 months – 1 year)

(a) Install the LNG facility at RSK, Gwalior.

(b) Advise the business model to other major users for replacing furnace oils with LNG. To be done on the RCD model.

K.2.2 Medium and Long Term (1 years and beyond)

(a) Install LNG facilities at all major users of furnace oils – PUs and workshops.

(b) Replace acetylene with LNG as cutting gas in all major PUs and workshops.

(c) Replace LNG for HSD in all stationery power plants based on ALCo Engine DG sets.

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