FEASIBILITY STUDY OF NATURAL GAS POWERED LOCOMOTIVE FOR BANGLADESH RAILWAY

by

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RECOMMENDATION OF THE BOARD OF EXAMINERS

The project entitled '**Feasibility study of Natural Gas powered locomotive for Bangladesh Railway**' submitted by A. B. M. Kamruzzaman, Roll No: 040513009(P), Session: 2005-06-07, has been accepted as satisfactory in partial fulfillment of the requirements for the degree of MASTER OF ENGINEERING on 8th November, 2008.

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It is hereby declared that this project or any part of it has not been submitted elsewhere for the award of any degree or diploma.

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ABSTRACT

Greater application of alternative fuels like CNG for transportation systems has been encouraged and supported by Hangladesh Government. A small reduction in fuel consumption through use of alternate cheaper fuel, efficient engine and improved technology can result in substantial savings in fuel bills. Besides cost aspects, the alternate fuel needs to be environment friendly without major input requirements in the existing system. As of date, more than one million vehicles are running with CNG in the world. Even in Bangladesh, realizing the adverse impact of increased environmental pollution, CNG has been adopted for public transportation in a big way. A large portion of the public transport vehicles including buses, taxis, auto rickshaws etc. have been converted into CNG powered vehicles. This has improved the air quality in major cities substantially. Application of Natural Gas as fuel for the railway has hot been addressed yet.

Bangladesh Railway now owns 285 locomotives, all run by diesel. The fuel consumed during the last fiscal year was about 35,759 metric tones, costing about taka 121 crore. As Bangladesh has no oil reserves, almost the entire amount of liquid fuel consumed annually in the country has to be imported. Since the mid 80's, a number of projects were launched in the US, Canada, and Russia to assess the viability of the natural gas fueled locomotive. These projects produced varying degrees of success and provided valuable insight for further development. In Peru, a mountain railway is being operated successfully with a dual fuel engine, which replaces about 50% of the diesel fuel with natural gas. Northern Railways, India is now conducting trial runs of locomotives with eco-friendly CNG in different routes.

In light of the above developments, and the uncertainty if world oil market and the high costs of imported fuel, Bangladesh Railway must look for other options. It is worthwhile conducting a feasibility study to see if natural gas can be successfully used in the railway sector as well. From the financial analysis of this report, it can be concluded that, cost reduction of CNG powered train is 30% compared to diesel fuel and Internal Rate of Return is 50%. The project has also addressed technical, economic and environmental issues for implementing natural gas powered locomotives for Bangladesh Railway.

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ABBREVIATIONS

BN	Burlington Northern Railway
BNSF	Burlington Northern Santa Fe Railway
BPC	Bangladesh Petroleum Corporation
BR	Bangladesh Railway
BTU	British Thermal Unit
CNG	Compressed Natural Gas
CO	Carbon Monoxide
CO2	Carbon Dioxide
DG	Dual gauge
ECI	Energy Conversion Insurance
EMD	Electro-Motive Division of General Motors
EPA	Environment Protection Agency
GM	General Motors
HP	Horse Power
HSD	High Speed Diesel
LaCHIP	Late Cycle High Injection Pressure
LNG	Liquefied Natural Gas
MK	Morrison Knudsen Corporation
NG	Natural Gas
NGL	Natural Gas Liquid
NOx	Oxides of Nitrogen
PM	Particulate Matters
RPM	Revolution per minute
RLM	Refrigerated Liquid Methane
SOx	Oxides of Sulfur
SwRI	Southeast Research Institute
THC	Total Hydrocarbons
UNEP	United Nations Environment Programme
UN	United Nations

CHAPTER I

INTRODUCTION

Bangladesh Railway is one of the largest and oldest government enterprises in the country, playing a vital role in the socio-economic development & industrialization of the country. It was established in 1862 named as Eastern Bengal Railway. Bangladesh Railway (BR), covering a length of 2855 route kilometers, now owns two types of locomotives Diesel Electric and Diesel Hydraulic. The total fleet as of 30th June 2007 comprised of 253 Diesel Electric and 32 Diesel Hydraulic locomotives [1]. Bangladesh Railway is expected to serve both as a commercial enterprise and as a public utility service. As a commercial enterprise, BR has an obligation to generate sufficient revenue to meet its cost. As a public utility service it has a responsibility to provide transport facilities to large number of passengers and movement of essential commodities for mass consumption. BR is also required to provide transport facilities in emergent situations like flood, cyclone, draught etc.

According to report of World Bank [2], Bangladesh Railway has embarked upon a comprehensive Railway Recovery Programme (RRP). It is supported by the Asian Development Bank (ADB) to increase efficiency and cost reduction. The reform program includes creation of a new corporate entity for BR. The communication ministry has now produced a railway act taking ADB suggestion. The act is seen as positive indication of the ministry's renewed commitment to structural change of BR.

In Bangladesh Railway, diesel is the only fuel for Locomotive. Most of the developed and developing countries introduced electric traction in their railway communication. Bangladesh cannot implement electric traction due to huge investment for infrastructure and shortage of electricity. According to Gupta [3], average electrification cost is 0.9 million US$ per route kilometer for single line and 1.45 million US$ per route Km for double line. Magnetic train cannot be considered a viable option yet for BR because it is still in experimental phase in the developed countries.

Railway companies would like to convert diesel Locomotive to NG or dual fuel Locomotive for minimizing cost and reduction of environment pollution. Natural Gas is cheap, available and it is able to produce the required calorific value like diesel. Technology of NG power locomotive is also available. According to a report on Indian Railway [4], CNG conversion cost per locomotive Rs. 36 Lac and comparing operating cost between diesel locomotive and CNG locomotive, savings will be Rs.23.8 Lac per year if CNG locomotive is used. Thus the cost of CNG conversion kit can be recovered in 18 months only giving annul rate of return of 66%. Again It has been reported that dual-fuelled locomotives could produce full diesel horsepower with emissions reduction of 65% NOx and SOx .

Bangladesh has the natural gas resource. There is no oil reserve in Bangladesh. Bangladesh imports oil from abroad through Bangladesh Petroleum Corporation (BPC), spending a lot of foreign currency. Bangladesh Railway is one of the big customers of BPC. During the year 2005-2006 Bangladesh Railway consumed 35,759 Metric Ton diesel oil only as locomotive fuel and expenses around 121 crore taka for locomotive fuel purpose [1]. If it is possible to convert diesel locomotive to Compressed Natural Gas (CNG) locomotive, it could use our natural resource, save money and get healthier Bangladesh.

The uncertainty of today's petroleum market with is declining oil reserves, on going tensions in oil producing nation, and environmental regularity activity soaring to new heights, has industry seeking new ways to provide power for fuel hungry, high horsepower applications. Among possible alternatives, natural gas stands alone as the one fuel that will benefit both the environment and the economy. The incentive today is not only fuel economy as before, but by Bangladesh's commitment to the Kyoto protocol pertaining to the reduction of greenhouse gases. When increasing energy costs are of concern, or excessive air pollution and strict emission regulations are an issue, compressed natural gas (CNG) or LNG are excellent solutions.

CNG has been successfully implemented in Bangladesh as fuel for motorized transportation such as cars, trucks and buses. Other modes of heavy transportation like railway or water ways have hot to been address yet. It is therefore newly to undertake a research to address the viability of using natural gas as fuel for the locomotive of BR. The technical, economical and regulatory aspects need to be examined.

Objectives:

The objective of the study has been subdivided as follows:

1. To assess technical options for converting diesel locomotive to natural gas powered locomotive.
2. To assess financial viability of NG powered locomotive in Bangladesh Railway and comparing with existing system.
3. To make recommendations whether BR should continue operation of trains with diesel-fueled locomotive or BR should introduce NG powered locomotive

Methodology:

To achieve the above objectives the following methods are adopted:

1. Study recent developments around the world in locomotive technology with respect to fuel usage.
2. Study the current practice and policy regarding fuel/energy source in Bangladesh Railway.
3. Study the Technical measures required for NG conversion of locomotives.
4. Study on nature of NG available in Bangladesh and its combustion characteristics
5. Study the opportunities to develop operational infrastructure requirement to operate NG powered trains.
6. Conduct Economic analysis of CNG powered locomotive. For this firstly one locomotive would be considered and taken data about conversion cost, operating saving cost and others related cost. A group of locomotive would be considered later in this report.
7. Study on Emissions and Environmental Enrichment due to NG powered trains.

CHAPTER 2

REVIEW OF LOCOMOTIVE TECHNOLOGY

A locomotive is a railway vehicle that provides the motive power for a train. The word originates from the Latin words *loco* means "from a place" and *motivus* means "causing motion".The term *locomotive engine* was first used in the early 19th century to distinguish between mobile and stationary steam engines.

A locomotive has no payload capacity of its own, and its sole purpose is to move the train along the tracks. Traditionally, locomotive's common function is push-pull operation, where a locomotive pulls the train in one direction from the front and pushes it in the other direction from the rear end of the train.

According to wikipedia, the free encyclopedia, the first successful locomotives were built by Cornish. In 1804 his unnamed steam locomotive hauled a train along the tramway of the Penydarren ironworks, near Merthyr Tydfil in Wales, UK . Although the locomotive hauled a train of 10 tons of iron and 70 passengers in five wagons over nine miles (14 km), it was too heavy for the cast iron rails used at the time. The locomotive only ran three trips before it was abandoned. The first commercially successful steam locomotive was rack locomotive, *The Salamanca*, built for the narrow gauge Middleton Railway in 1812.

2.1: Types of Locomotive

Locomotives may generate their power from different fuel such as wood, coal, petroleum or natural gas or they may take power from an outside source of electricity. It is common to classify locomotives by their source of energy. The common ones include:

a) Steam locomotive

b) Diesel locomotive

    I. Diesel-electric locomotive
    II. Diesel-mechanical locomotive
    III. Diesel-hydraulic locomotive

c) Gas turbine locomotive

d) Electric locomotive

e) Magnetic Levitation (Maglev train)

f) Hybrid Locomotive

A locomotive has no payload capacity of its own. In contrast, some trains have self-propelled payload-carrying vehicles. These are not normally considered locomotives and may be referred to as multiple units, motor coaches or railcars.

2.1.1: Steam Locomotive

In the 19th century the first railway locomotives were powered by steam, usually generated by burning coal. Because steam locomotives included one or more steam engine, they are sometimes referred to as "steam engines".

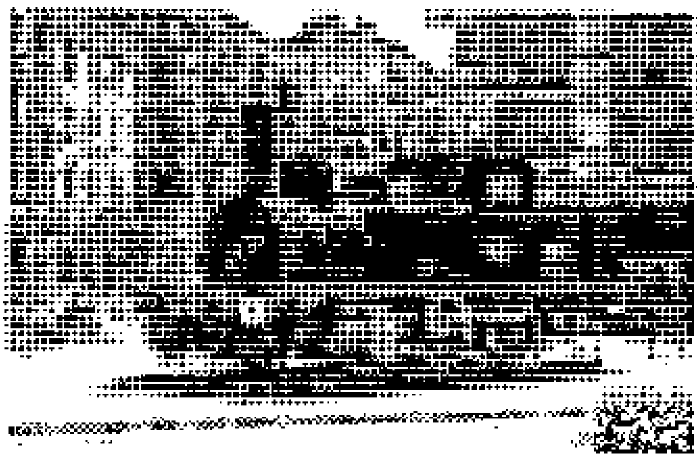


Fig 1: steam locomotive

The reciprocating steam locomotive is a self-contained power unit consisting essentially of a steam engine and a boiler with fuel and water supplies. Superheated steam, controlled by a throttle, is admitted to the cylinders by a suitable valve arrangement, the pressure on the pistons being transmitted through the main rod to the driving wheels. The driving wheels, which vary in number, are connected by side rods. Steam locomotives are usually classified under the Whyte system, that is, by the number and arrangement of the wheels. For example, an engine classified as 2–6–0, which means, it has one pair of wheels under the front truck, three pairs of coupled or driving wheels and no wheels under the trailing truck. In some cases the truck wheels of the tender (fuel carrier) are added.

The steam locomotive remained by far the most common type of locomotive until after World War II. Before the middle of the 20th century, electric and diesel-electric locomotives began replacing steam locomotives. Steam locomotives are less efficient than their more modern diesel and electric counterparts and require much greater manpower to operate and service. British Rail figures showed the cost of crewing and fuelling a steam locomotive was some two and a half times that of diesel power, and the daily mileage achievable was far lower. As labour costs rose, particularly after the second world war, non-steam technologies became much more cost-efficient. Steam locomotives were in regular use until 2004 in the People's Republic of China, where coal is a much more abundant resource than petroleum for diesel fuel. Such locomotives are still in operation in scotland. The few steam locomotives that remain in operation in developed nations are mostly nostalgic relics used chiefly to pull tourist trains. One of the steam locomotive named *Fairy Queen*, built in 1855 runs between New Delhi and Alwar in India and is the oldest steam locomotive in regular (tourist-only) service in the world and the oldest steam locomotive operating on a mainline.

2.1.2: Diesel Locomotive

Diesel Locomotive contains an internal combustion engine. It requires some type of power transmission system to couple the output of the prime mover to the driving wheels. In the early days of diesel railroad propulsion development electric, hydraulic and mechanical power transmission systems were employed with varying degrees of success. Of the three, electric transmission proved to be most practical. Some diesel-hydraulic locomotives were manufactured for lower power applications.

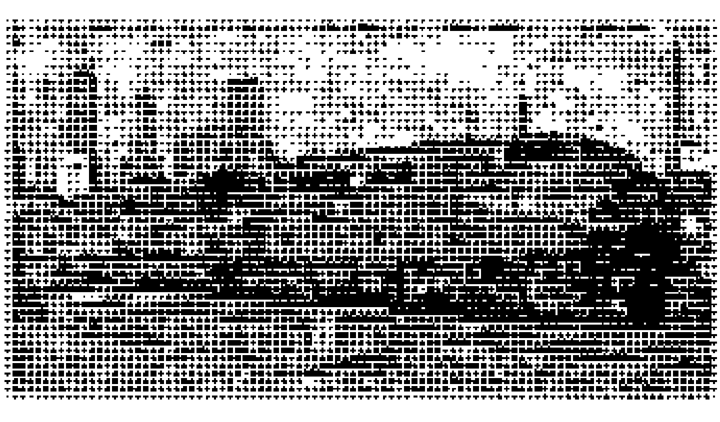


Fig 2: Diesel Locomotive

I. Diesel-electric locomotive: Diesel-electric locomotives were introduced in 1924, and have become the most widely used type of locomotive. The modern diesel-electric locomotive is a self-contained, electrically propelled unit. Like the electric locomotive, it has electric drive, in the form of traction motors driving the axles and controlled with electronic controls. It also has many auxiliary systems for cooling, lighting, heating, and braking. It differs from electric locomotive principally in that it has its own generating station instead of being connected to a remote generating station through overhead wires or a third rail. The generating station consists of a large diesel engine coupled to an alternator or generator that provides the power for the traction motors. These motors drive the driving wheels by means of spur gears. The ratio of the gearing regulates the hauling power and maximum speed of the locomotive.

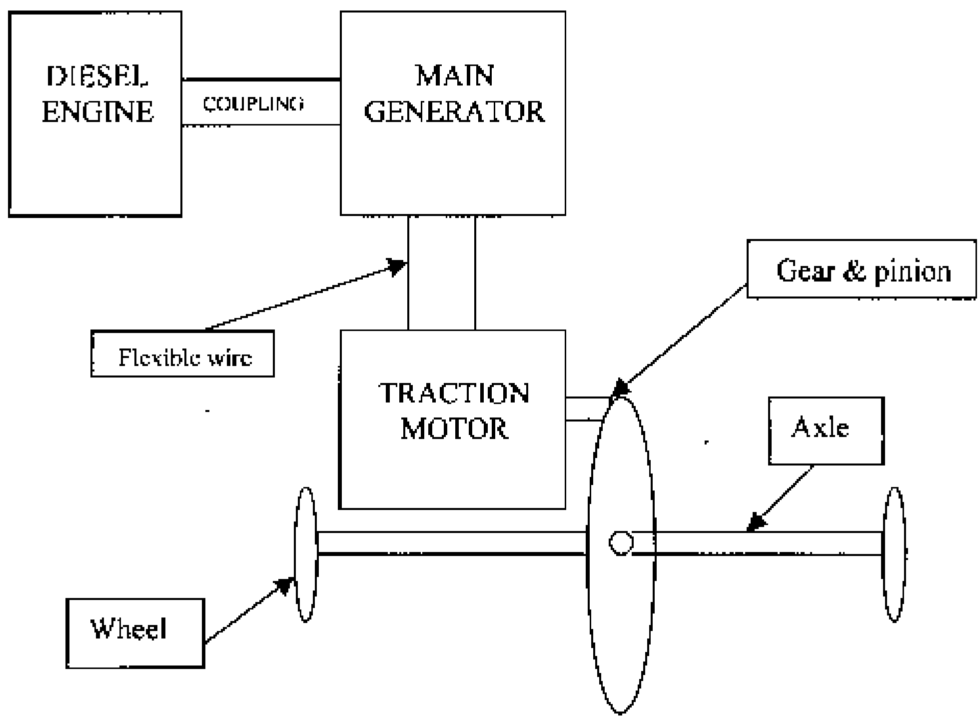


Fig 3: Basic principle of DE Locomotive

Operation of a Diesel Electric Locomotive is described as follows:

1) Storage Battery drives the fuel pump which draws fuel oil from the tank and supplies to the engine
2) The engine is started using two starting motors which electric source is supplied from the storage battery.
3) Engine drives
    a. Main generator
    b. Auxiliary generator
    c. Compressor
    d. Cooling fan
    e. Traction motor blower
4) Auxiliary generator charges the battery and supplies current to low voltage circuits.
5) Low voltage current is supplied to all relays, switches etc through electric cabinet.
6) The main generator transforms the engine mechanical power into high voltage electrical power (nominal rectified voltage 600VDC and maximum continuous current rating 3200A) which is sent to two or three traction motors located in each truck and geared to the driving axles.
7) The engineman's control station includes the control levers, brakes lever and switches necessary for operating the locomotive.
8) The electrical cabinet contains various switches, fuses, contractors and relays necessary to control the operation of the locomotive.
9) The engine governor controls the engine speed as directed by the throttle lever.
10) The load regulator controls the engine power so that it does not send more or less power to the main generator than what it should be for each throttle position.
11) The air compressor is connected to the main generator and pumps air only when necessary.
12) One or two water pumps mounted on the engine circulate water through the engine cooling system. The water is cooled by a fan and temperature is automatically controlled by a thermostatic switch
13) Lubricating oil is circulated through the engine and oil cooler via filter and strainer by one or two oil pumps mounted on the engine.

II. Diesel-mechanical locomotive: Diesel-mechanical locomotives have a direct mechanical link consisting of a clutch and a series of gears and shafts between the engine and the wheels, similar to the transmission in an automobile. Because mechanical drives deliver less power to the wheels than diesel-hydraulic and diesel-electric systems, they are only used with the smallest locomotives.

III. Diesel-hydraulic locomotive: The Diesel Hydraulic Locomotive differs from the Diesel Electric Locomotive only by the transmission system. In diesel-hydraulic locomotives the engine drives a torque converter, which uses fluids under pressure to transmit and regulate power to the wheels. Hydraulic drives are widely used in some countries, such as Germany.

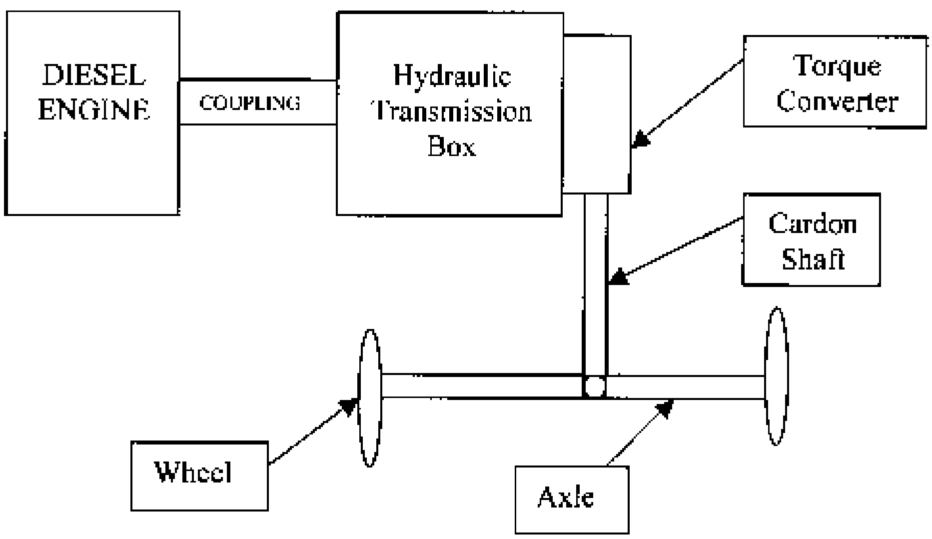


Fig 4: Basic principle of Diesel-hydraulic locomotive

Starting in the 1940s, the diesel-powered locomotive began to displace steam power. Diesel locomotives require considerably less maintenance than steam, with a corresponding reduction in the number of personnel needed to keep the fleet in service. The best steam locomotives spent an average of three to five days per month in the shop for routine maintenance and running repairs. Heavy overhauls were frequent, often involving removal of the boiler from the frame for major repairs. In contrast, a typical diesel locomotive requires no more than eight to ten hours of maintenance per month, and may run for many years between major overhauls.

2.1.3: Gas turbine locomotive

A gas turbine-electric locomotive, or GTEL, is a locomotive that uses a gas turbine to drive an electrical generator or alternator. The electric current thus produced is used to power traction motors. This type of locomotive was first experimented with in 1920 but reached its peak in the 1950s to 1960s.

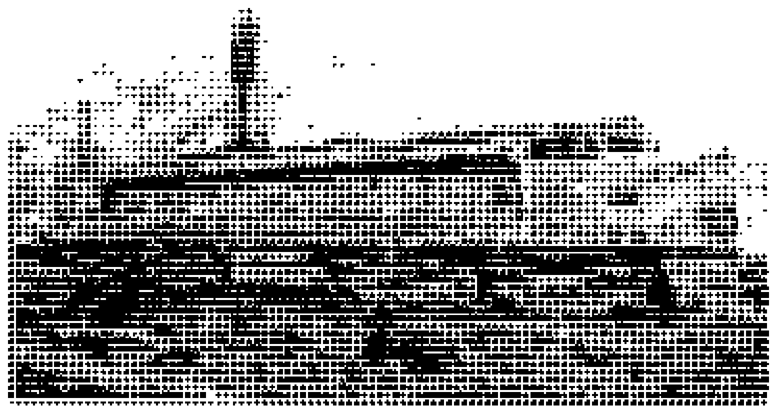


Fig 5: Gas turbine-electric locomotive

A turbine offers some advantages over a piston engine. The number of moving parts is much smaller. A turbine of a given power output is also physically smaller than an equally powerful piston engine, allowing a locomotive to be very powerful without being inordinately large.

Gas turbine locomotives are very powerful, but also tend to be very loud. After the 1973 oil crisis and the subsequent rise in fuel costs, gas turbine locomotives became uneconomical to operate, and many were taken out of service. This type of locomotive is now rare.

2.1.4: Electric Locomotive

Electric locomotives range from the small type used in factories and coal mines for local hauling to the large engines used on railroads. Electric locomotives generally have two or more motors. Power is collected from an electric trolley, or pantograph, running on an overhead wire or from a third rail at one side of the track.

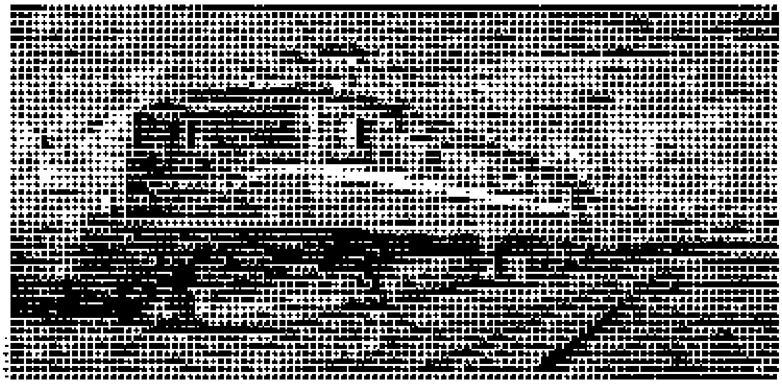


Fig 6: Electric locomotives

While the capital cost of electrifying track is high, electric trains and locomotives are capable of higher performance and in some cases lower operational costs than steam or diesel power. Electric locomotives, because they tend to be less technically complex than diesel-electric locomotives, are both easier and cheaper to maintain and have very long working lives. Although highly efficient, its use is limited by the cost of electric substations and overhead wires or third rails.

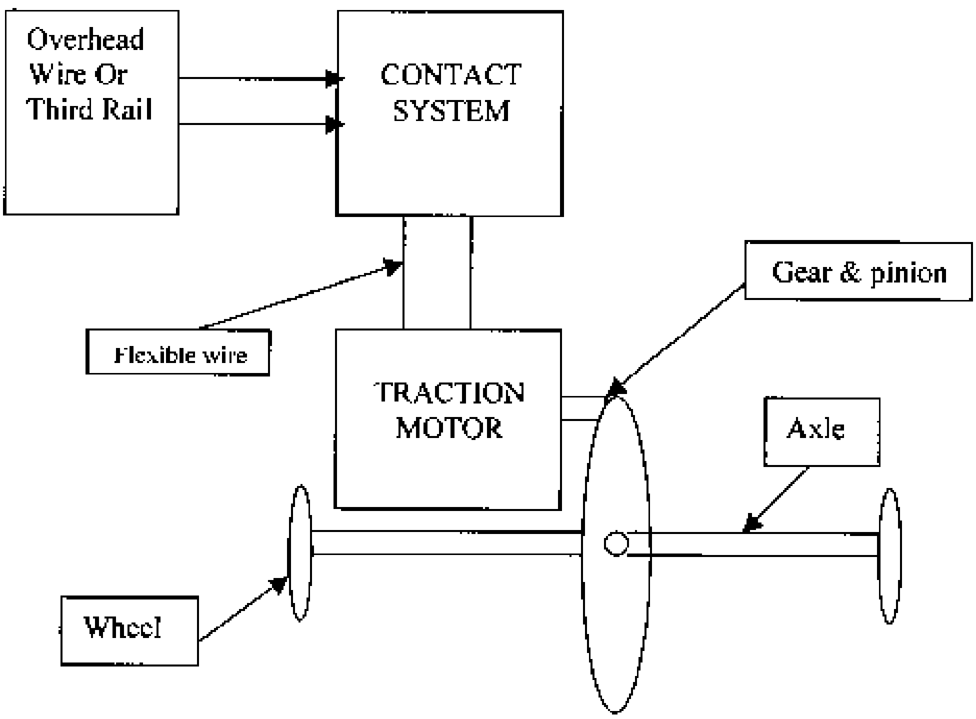


Fig 7: Basic principle of Electric locomotive

Some electric locomotives can also operate with battery power to enable short journeys or shunting on non-electrified lines or yards. Battery-powered locomotives are used in mines and other underground locations where diesel fumes or smoke would endanger crews and where external electricity supplies cannot be used due to the danger of sparks igniting flammable gas.

2.1.5: Magnetic levitation (Maglev train)

The newest technology in trains is magnetic levitation (maglev). These electrically powered trains have an open motor which floats the train above the rail without wheels. This greatly reduces friction. Special type of track used which create north and south poles alternatively by electro magnitism and moving forward the train. Very few systems are in service and the cost is very high. The experimental Japanese magnetic levitation train has reached 581 km/h (361 mph) .

Fig 8: maglev train

The first commercial maglev trains ran in the 1980s in Birmingham, United Kingdom, providing a low-speed shuttle service between the airport and the railway station. Despite the interest and excitement, the system was shut down due to a lack of spare parts and replaced by wheeled cablecars a few years later.

2.1.6: Hybrid Locomotive

A hybrid locomotive is a Locomotive that uses an on-board rechargeable energy storage system (RESS) and a fuelled power source for propulsion. General Electric Company (GE) unveiled a prototype hybrid locomotive for freight trains on May 24th, 2007 in Los Angeles, California.

Hybrid trains typically are powered either by Fuel Cell technology or the diesel-electric hybrid which reduces fuel consumption through regenerative braking and switching off the hydrocarbon engine when idling or stationary.

2.2: Recent development on Locomotive

There are some key aspects that need to be considered when selecting commercial Locomotive. They include:

- Energy Source available
- Nature of the operations
- Emissions
- Installation and operating cost
- Infrastructure, etc.

Taking consideration all these factors, many locomotive manufacturing companies are trying to make new types of locomotive. Parry People Movers (locomotive manufacturing company, UK) make an experimental Locomotive powered by energy stored in a flywheel. The flywheel is powered from an onboard battery-driven motor or internal combustion engine and is also recharged through regenerative braking. A proposed alternative is to recharge the flywheel from external electric motors installed at station stops. Although this would increase installation costs it would substantially reduce the weight of the vehicles. Parry People Movers have been tested on several railways. The first mainstream timetable service for the flywheel locomotive was launched in February 2006 on the short link between Stourbridge junction and Stourbridge Town in the United Kingdom.

One of the newest technologies in trains is magnetic levitation (maglev). Cost of the maglav train is very high.These electrically powered trains floats above the rail without wheels. This greatly reduces friction. It moves forward with very high speed by creating north and south pole alternatively between train and rail. Avarage speed of magnetic levitation train is 550 to 700 km/h.

General Electric Company's (GE) engineers are designing a hybrid diesel-electric locomotive that will capture the energy dissipated during braking and store it in a series of sophisticated batteries. That stored energy can be used by the crew on demand – reducing fuel consumption by as much as 15 percent and emissions by as much as 50 percent compared to most of the freight locomotives in use today. In addition to environmental advantages, a hybrid will operate more efficiently in higher altitudes and up steep inclines.

Dual fuel Locomotive is the another new type of Locomotive. This type of locomotive can use two type of energy. Dual mode locomotives can operate using both electric (catenary) and diesel power or diesel fuel and gas fuel.

When increasing energy costs are of concern, or excessive air pollution and strict emission regulations are an issue, natural gas (NG) is an excellent alternative fuel for locomotive. A number of projects were launched in the US and Canada to assess the viability of the natural gas fueled locomotive and they already introduced natural gas powered locomotive in railway communication. Peru unveiled the world's first train powered by environmentally friendly compressed natural gas (CNG) in 2005. Northern Railways, India is now conducting trial runs of locomotives with eco-friendly CNG.

2.3: World Railways Statistics

The world's longest rail line is in Russia. It extends about 5,600 miles (9,010 kilometers) and connects Moscow and Vladivostok. The total tracks of the world's main railroad routes would stretch about 750,000 miles (1,207,000 kilometers) about 3.25 times the distance from the earth to the moon [5]. Some information about world railway is given in table 1 to 3:

Table 1: Length of World Railways

SL. No.	Country	Length of Route (Km)	Length of per capita (m)	Length of per Square Km (m)
1	U. S. A.	226,612	0.776	24.7
2	Russia	87,157	0.610	5.1
3	China	75,438	0.058	8.1
4	India	63.221	0.058	21.3
5	Germany	48,215	0.585	138.1
6	Canada	48,068	1.452	5.3
7	Australia	38,550	1.902	5.1
8	Argentina	31,902	0.799	11.7
9	France	29,370	0.482	53.8
10	Brazil	29,295	0.156	3.5
11	Japan	23,474	0.184	62.6
12	Poland	23,072	0.599	75.8
13	South Africa	20,872	0.472	17.1
14	Italy	19,460	0.335	66.2
15	Mexico	17,665	0.164	9.2
16	UK	16,567	0.273	68.6
17	Iran	8,367	0.122	5.1
18	Pakistan	8,163	0.049	10.5
19	Indonesia	6,458	0.026	3.5
20	Korea (North)	5,235	0.226	43.5
21	Myanmar	3,955	0.083	6.0
22	**Bangladesh**	**2,855**	**0.020**	**21.0**
23	Iraq	2,272	0.085	5.3
24	Malaysia	1,890	0.078	5.8
25	Sri Lanka	1,449	0.072	22.4
26	Nepal	59	0.002	0.4

Railways play a vital role in communication sector of any country. Rail transportation is cheap compare to road transportation. Some rail transportation statistics have shown in table.

Table 2: Passenger-Kilometers carried by Railway

Country	No. of Passenger-Km
Japan	396,336,000,000
China	363,276,000,000
India	316,728,000,000
Russia	227,100,000,000
Ukraine	70,884,000,000
Bangladesh	**4,160,000,000**

Note:

- Passenger-Km signifies the multiple of number of passengers times their distance traveled in Km's.
- Japan figures are high due to its high population density and over-reliance on trains
- The figure is higher for China, India and Russia as distances are higher

Table 3: Ton-Kilometers carried by Railway

Country	No. of ton-Km
United States	1,759,464,000,000
China	1,242,600,000,000
Russia	1,195,164,000,000
Canada	279,510,000,000
India	252,588,000,000
Bangladesh	**817,000,000**

Note:

- Ton-Km signifies the multiple of tons of freight transported times their distance traveled in Km's.
- The figure of Bangladesh very poor as other countries has a bigger geographical area.

CHAPTER 3

OVERVIEW OF BANGLADESH RAILWAY (BR)

Bangladesh Railway was established in 1862. It was named Eastern Bengal Railway. Construction of 53.11 km of Broad Gauge (BG) line between Darsana and Jahati of Kustia district was started in November, 1862. First Meter Gauge (MG) line was constructed from Sara (Pabna) to Chilahati (Nilphamari) and Parbatipur to Dinajpur during the period from 1874 to 1879. Railway connection (Meter Gauge) between Dhaka and Narayangong, a distance of 14.98 km was being constructed by Dhaka State Railway in 1885, which was later on merged with Eastern Bengal Railway. In 1961, Eastern Bengal Railway was renamed as Pakistan Eastern Railway. After liberation war in 1971, it was again renamed as Bangladesh Railway. That time the total route kilometer was 2858.23 km. In the beginning of 21st century, BR was beginning construction dual gauge (DG) line. Now the total route kilometer of BR is 2855 km, among this 1830 km is MG, 660 is BG and 365 km is DG [1].

Table 4: Route Kilometer of BR

Year July-June	Figures are in kilometers		
	Broad Gauge	Meter Gauge	Total
1969-1970	1935.16	923.07	2858.23
1996-1997	1822.12	883.89	2706.01
2000-2001	1832.12	936.25	2768.37
2005-2006	1829.74	660.22 + 365 (DG)	2854.96

Up to 1953, there were only steam locomotives in Eastern Bengal Railway (Bangladesh Railway). In 1953, first diesel locomotive was introduced in Bangladesh Railway. At the time of liberation war, there were 486 locomotive in BR. Among that 343 were steam locomotive and 143 were diesel locomotive. By the end of the 1970s-1980s, Bangladesh Railway had completely replaced steam locomotives by diesel locomotive. Bangladesh Railway now owns 285 locomotives, all run by diesel.

Bangladesh Railway is managed by 35,172 regular staff, is Government owned and Government managed transportation agency of the country. BR now owns two types of diesel locomotives, Diesel Electric and Diesel Hydraulic, both use diesel as fuel. Heavy repair and overhauls of diesel locomotives are done at central locomotive workshop (CLW), Parbotipur and diesel workshop, Dhaka, Chittagong and Parbotipur. Some important information of BR is given in table 5.

Table 5: Information of BR

Item	Figure
Route Kilometers	2,854.96 Km
Track Kilometers	4,442.95 Km
Number of Stations	454
Passenger Carried per year	42.3 Million
Tones Carried per year	3.21 Million
Number of Passenger Train	235 / Day
Number of Freight Train	47 / Day
Number of Passenger Coach	1408
Number of Wagon	10,236
Number of Locomotive	285

During 2006-07 fiscal year, total earning of BR was 500 crore taka and total operating expenses was 800 crore. Expenses on general administration were 16.25%, repair and maintenance 35.41%, operation staff 14.88%, operation fuel 13.25% and others 20.21%. In this situation, Bangladesh Railway has embarked upon a comprehensive railway recovery program in order to improve its financial performance through increased efficiency and cost reduction. Asian Development Bank (ADB) is doing work on reform process of BR [2]. The principle of the reform process is to transform BR into a more commercial organization like corporation.

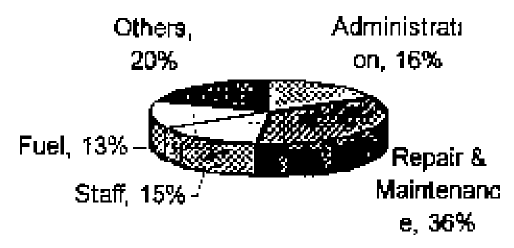


Fig 9: Expenses of BR

3.1: Types of Locomotive in BR

From beginning to mid 20th century, Eastern Bengal Railway (Bangladesh Railway) had been using only steam locomotive. In 1953, first diesel locomotive was introduced in East Pakistan Railway (Bangladesh Railway). At the time of liberation war (1971), there were 486 locomotive in BR. Among them 343 were steam and 143 were diesel locomotives. Steam Locomotives were running in BR up to 1981. Bangladesh Railway now owns 285 locomotives, all run by diesel.

There are two types of rail line in Bangladesh Railway; i) meter gauge and ii) broad gauge. For this reason, two different sizes of locomotives are needed. Both sizes of locomotive are diesel locomotive that run by diesel fuel. Those diesel locomotives are two types i) Diesel Electric ii) Diesel Hydraulic. Description of Diesel Electric Locomotive and Diesel Hydraulic Locomotive has given in section 2.1.2 of this report. Locomotive position of BR is given in table 6:

Table 6: Locomotive position of BR

Type of Locomotive	Present Holding		
	Broad Gauge	Meter Gauge	Total
Diesel-Electric	68	185	253
Diesel Hydraulic	10	22	32
Total	78	207	285

Details of locomotives used in Bangladesh Railway are given in appendix-A.

3.2: Energy source

Fuel is essential for operation of train services in the railway. Present day the most widely used fuel in Locomotive in Bangladesh is high speed diesel oil. Bangladesh Railway import diesel oil from abroad through Bangladesh Petroleum Corporation (BPC), spending a lot of foreign currency. Bangladesh Railway is one of the big customers of BPC. During the year 2004-2005 Bangladesh Railway consume 35,373 Metric Ton diesel oil only as locomotive fuel and expenses around 120 crore taka for locomotive fuel purpose [1]. According to website of BPC, total consumption of diesel in Bangladesh is 22, 64,843 Metric Ton. Bangladesh Railway consumes 1.6% diesel of total consumption in Bangladesh.

3.2.1: Procurement and storage

An agreement has been arranged for procurement and supply of high speed diesel (HSD) oil to Bangladesh Railway for operational purpose. In this connection the oil companies like Padma, Meghna and Jamuna have been nominated for supplying of HSD oil from Patenga and Daulatgonj at Khulna. Accordingly railway administration has been receiving regular supply of fuel oil from the above companies through railway transportation. At the loading point of above companies Railway Tank Wagons are loaded in presence of representatives drawn from Mechanical department, Security department of BR and one representative from the respective oil companies. After loading and sealing the fuel tank, the representatives arrange to dispatch the tank wagon to the respective stockholder to different Loco sheds. List and location of different loco sheds are shown in appendix-B. Every shed has storage tank for preservation of minimum 15 days oil in hand. All the tank wagons allotted for the respective sheds are decanted into storage tanks with proper recording in the fuel storage resister. There is a system in every Loco shed for issuing of fuel oil to the Locomotive. Such issue of fuel oil is conducted by the fuel pump from storage tank through dehydrator.

3.2.2: Properties of HSD Oil

As crude oil is refined, approximately 44% is gasoline, 36% is diesel and the balance is kerosene, lubricants, etc. The characteristics or a property of diesel fuel is determined by heat value, specific gravity, flash point, viscosity, volatility carbon residue etc.

Commercially, by American society of testing and standards, there are three grades or classifications of automotive diesel fuels. There are known as Grade 1-D, Grade 2-D and Grade 4-D. At one time there was a Grade 3-D, but that has been discontinued. The properties of diesel fuel that used in BR are very similar to Grade 2-D. The required cetane number of this fuel is minimum 40. The characteristics or properties of diesel fuel used in Bangladesh Railway are given in table:

Table 7: The characteristics or properties of diesel fuel used in BR

1.	Heat Value	12000 to 14000BTU/lb
2.	Specific Gravity	0.81 to 0.85
3.	Minimum Flash Point	125 deg. F (52 deg. C)
4.	Pour Point	40 deg. F (5 deg. C)
5.	Viscosity	1.8 to 5.8 cs at 100 deg. F
6.	Volatility (90% fuel distilled off)	650 deg. F (max)
7.	Final Boiling Point	700 deg. F (max)
8.	Ignition Quality (cetane number)	40 (min)
9.	Ash (weight %)	0.02%(max)
10.	Carbon Residue (weight %)	0.35%(max)
11.	Sulphur Content (weight %)	0.50%(max)
12.	Sediment and water (weight %)	0.05%(max)

3.2.3: Rules for Transportation of HSD Oil and Explosive

According to operating manual of Bangladesh Railway, the rules of attaching of vehicles containing explosives and inflammable liquids to good trains are as follows:

a) Tank wagon and other vehicles, containing explosives and inflammable liquids , when carried by goods trains, shall be marshaled as far away as practicable from the engine and shall be preceded and followed by not less than three wagons not loaded with similar goods. Not more than three vehicles containing explosives should be hauled by one train and such vehicles shall be close coupled to the adjoining vehicles and to each other. the divisional superintendent, may, however, permit five vehicles containing explosives to be hauled by a goods train in urgent cases. This must be reported, in due course, to headquarter, whenever such permission is granted by them.

b) During shunting, vehicles loaded with explosives must be separated from the engine by at least three vehicles not loaded with explosive or other inflammable goods. This precaution is not necessary with powder vans. Shunting of such vehicles must be supervised by the yard foreman or the station master on duty at station where shunting staff is not provided, who shall be held responsible for the observance of these orders.

c) Loose shunting of vehicles containing explosives is strictly prohibited.

According to traffic manual (part one), the following rules must be acted up to in dealing with vehicles loaded with explosives or dangerous goods.

Explosives may be carried subject to the following conditions

a) By mixed train provided;

- That not more than one power van is forwarded by any one train
- That the powder van is preceded and followed by three goods vehicles, not loaded with explosives or other traffic of an inflammable nature
- That the powder van is close coupled to the adjoining vehicles.

b) By goods trains provided not more than five powder vans containing explosives shall be conveyed by any one train.

c) No explosive shall be conveyed by passenger train except of the kinds and in the manner specified in schedule 1 or as authorized in the rules of the red pamphlet.

d) When a train is being marshaled. wagons loaded with explosives may be shunted by a locomotive, only if they are separated from the engine by not less than three wagons containing neither explosives nor easily inflammable substance. This precaution is not necessary with powder vans. The speed of these movements must be restricted to five miles an hour; they must be superintended by a duly authorized officer, who shall be held responsible for the observance of these orders. Loose shunts are strictly prohibited with any vehicle containing explosives.

Natural gas carrying wagon or vehicle would be treated as explosive or dangerous goods. Those rules also applicable for CNG tender car or CNG cascade bearing vehicle. One point is that those rules are very old and applicable when CNG carry as carrying material not as fuel. Considering the technology advancement in using alternating fuel, Bangladesh Railway should needed to take initiative for changing rules or introducing new rules for moving CNG tender car or CNG cascade bearing vehicle to use CNG as fuel.

3.3: Energy source options for BR

Today's petroleum market is unstable with declining oil reserves and on going tensions in oil producing nation. Environmental regularity activity is going all over the world. This situation, industries are seeking new ways to provide power for fuel hungry, high horsepower application. In Bangladesh Railway, diesel is the only fuel for Locomotive. Bangladesh should find the other options to improve energy source for railway operation.

By the end of the 1970s-1980s, most countries had completely replaced steam locomotives due to cost of crewing and fuelling. Bangladesh is going to produce coal from own mine. Though Bangladesh use it's own coal as fuel, it would not be viable to operate steam Locomotive because of its low efficiency. On the other hand, there is no steam locomotive in BR. Locomotive manufacturing companies do not interested to make steam locomotive and it's spare parts. Finaly, steam locomotive is not envirnment friendly.

Most of the developed and developing countries introduced electric traction in their railway communication. Bangladesh cannot implement electric traction due to huge investment needed for infrastructure and shortage of electricity. According to Gupta [4], average electrification cost is 0.9 million US$ per route kilometer for single line and 1.45

million US$ per route Km for double line. Again, it would need to buy electric locomotive, because there is no electric locomotive in BR.

The newest technology in trains is magnetic levitation (maglev). Very few systems are in service and the cost is very high. For this reson, it is quite impossible to introduce maglev train in BR because still now it is in experimental phase in developed country.

Bangladesh has the natural gas resource. There is no oil reserve in Bangladesh. When increasing energy costs are of concern, or excessive air pollution and strict emission regulations are an issue, natural gas (NG) is an excellent alternative fuel for locomotive. Natural Gas is cheap, available and it would able to produced required calorific value like diesel. Technology of NG power locomotive is also available. Greater application of alternative fuels for transportation systems has been encouraged and supported by Bangladesh Government as well. Thus it approve that apart from diesel, CNG is the only viable option for alternative energy source for BR.

CHAPTER 4

CONVERSION OF LOCOMOTIVE

4.1: History of NG Conversion

In the mid 1980's, a number of projects were launched in the US and Canada to assess the viability of the natural gas fueled locomotive. A research project was attempted by Bombardiar (Locomotive manufacturing company) to review the use of NG as an alternative fuel for locomotives. Southwest research institute conducted a similar project on a two-cylinder EMD (Electro-Motive Division of General Motors) engine. A demonstration from 1992 to 1995 the Burlington Northern Railroad used two GM (General Motors) locomotive were converted to NG operation using dual fuel system made by EFI [6]. In 1984, Russia started a program to develop NG fuelled locomotives. In 1993, 4 type of NG fueled locomotive were commissioned in the Russian Railway Industry. Germany has successfully developed 165KW CNG (Compressed Natural Gas) locomotives and tested them in rail yard switching operation. Japan, Finland and Czech Republic are also designing locomotives that operate on natural gas [7].

Energy Conversion Insurance (ECI) started to develop natural gas and dual fuel technology in 1985 and has worked on over 80 projects, mostly dealing with liquefied gas, with Burlington Northern Santa Fe Railway (BNSF). In 2000, they completed a project creating a 100% compressed natural gas system for the Napa Valley Wine Train. ECI (energy Conversion Inc.), USA finished a project for a mountain railroad in Peru where they implemented a GE dual fuel engine, which replaces about 50% of the diesel fuel with natural gas. According to Reuters; June 17, 2005, LIMA - Peru on Thursday unveiled the world's first train powered by environmentally friendly compressed natural gas (CNG). On June 18, 2005 Peru's Vice-President David Waisman visited Ferrocarril Central Andino, to launch its first diesel loco converted to operate on compressed natural gas.

Two cost analysis projects were conducted in the United States between 1992 and 1994 to address this issue for NG fuelled locomotives. According to a cost analysis assessment performed by Southeast Research Institute (SwRI), conversion of small fleet to operate on NG would not be economically feasible. The benefits from the cost of fuel and fuelling interval would be too small to offset the large cost of capital equipment purchases (e.g. locomotive, NG conversion, tender car). Based on this report. the conversion can only be profitable if large numbers of locomotives are converted to NG. In 1994, a cost analysis report was prepared for Burlington Northern Railway (BN) by Industrial Engineering to determine the fuel cost saving if diesel fuel is replaced by RLM (Refrigerated Liquid Methane). Based on this report, if the RLM was purchased at $0.22 per gallon the cost of moving BN's coal trains with NG fuelled locomotives would have been $6756 per round trip. Using straight diesel fuel for the same trip would have been $9774. The difference in fuel cost alone meant an almost 31% reduction in fuel cost per round trip [7].

In a move to use non-conventional fuels, Northern Railways, India is now conducting trial runs of locomotives with eco-friendly CNG. A feasibility study and technical report on the project was done in July 2004. The report was submitted to and subsequently cleared for trials by the Research, Design and Standards Organization of India. After the clearances, work on structural modification and the retro fitting of CNG kits was started in November 2004 at Shakurbasti Diesel Shed. They have successfully conducted trial runs of railway engines with CNG and trials are now being done on the Delhi-Rohtak and Delhi-Rewari routes. A report on CNG as an alternate fuel for railway traction, CNG conversion cost per locomotive Rs. 36 Lac. Comparing operating cost between diesel locomotive and CNG locomotive, Savings will be Rs.23.8 Lac per year if CNG locomotive is used. Thus the cost of CNG conversion kit shall be recovered in 18 month only giving annul rate of return of 66% [3].

4.2: Review of NG Fueled Engine Technology

A comprehensive literature search on natural gas fueled engine technology was conducted to obtain a thorough understanding of the technology. Many research works in this area had been done and the evolution that have taken place in this area since 2000. Technical papers relevant to this work are provided in the reference section. NG fueled engine could be divided into two; one is operated by only gas and another is operated by dual fuel (diesel & CNG/LNG). The engine modifications to run on 100 percent NG can be accomplished by gas mixing or by direct injection. Those operating on dual fuel can be modified using low-pressure early-cycle injection or high-pressure late-cycle injection system. These technologies are described in the following sub-sections.

4.2.1: Natural Gas combustion system

a) Gas Mixing

Gas mixing is accomplished by feeding NG to the engine through a fuel mixer or an NG injector in the intake manifold that result in a homogeneous mixture. Such a system requires a spark plug as an ignition source. For optimum operation, exact control of ignition timing is crucial. The timing must be optimized over the entire speed-load range. Introducing the NG into the intake manifold reduces the volumetric efficiency and maximum power of the engine. This would make it susceptible to explosion at high load operation or with changes in the gas composition. During part-load operation, the intake air must be throttled, which results in corresponding brake specific fuel consumption losses. Since NG is mixed with the intake air, some of it is lost during the valve overlap period of the scavenging process, producing high HC emissions.

In 1993, MK Rail Corporation introduced MK 1200G switcher locomotive which was a LNG mono fuel locomotive powered by a Caterpillar engine [6]. This Caterpillar engine is a turbocharged, after cooled, spark-ignited, lean-burn engine producing 1000kW. The intake gas mixing technique is used to feed the LNG to the engine. The low exhaust emissions of this LNG engine made it attractive for operation in the Los Angeles area. It should be mentioned that the Union Pacific Railway and Burlington Northern Santa Fe Railway Company have also operated two of these units in daily switching service in the Los Angeles area.

b) Direct Injection

NG is directly injected into the cylinder of an engine in this method. In this case, an ignition source is also required: a spark plug or a glow plug. NG can be introduced into a pre-chamber situated in the cylinder head and then ignited. As the mixture burns, it expands into the main chamber where additional NG may be injected but the overall air/fuel ratio remains lean. For optimum operation, ignition timing must be accurately controlled over the entire operating range. The in-head pre-chamber increases heat rejection to the cooling water, which increases fuel consumption. This engine design has been used to convert a number of small size engines for medium duty on-highway applications.

Figure (10) illustrates this type of system. Pre-chamber NG engine conversions are not expected to be applied to locomotives, since reliable, repeatable ignition with extended durability can not be achieved. NG can be directly introduced into the cylinder. This approach eliminates the need for a pre-chamber. This type of combustion system has been the subject of much research in automotive applications using spark plugs, but very little in heavy-duty applications. It suffers from several drawbacks. In heavy-duty applications, spark plug erosion and durability are major problems. In addition, controlling the amount of air circulation in the cylinder to provide consistent combustion over the entire speed / load range presents a significant challenge.

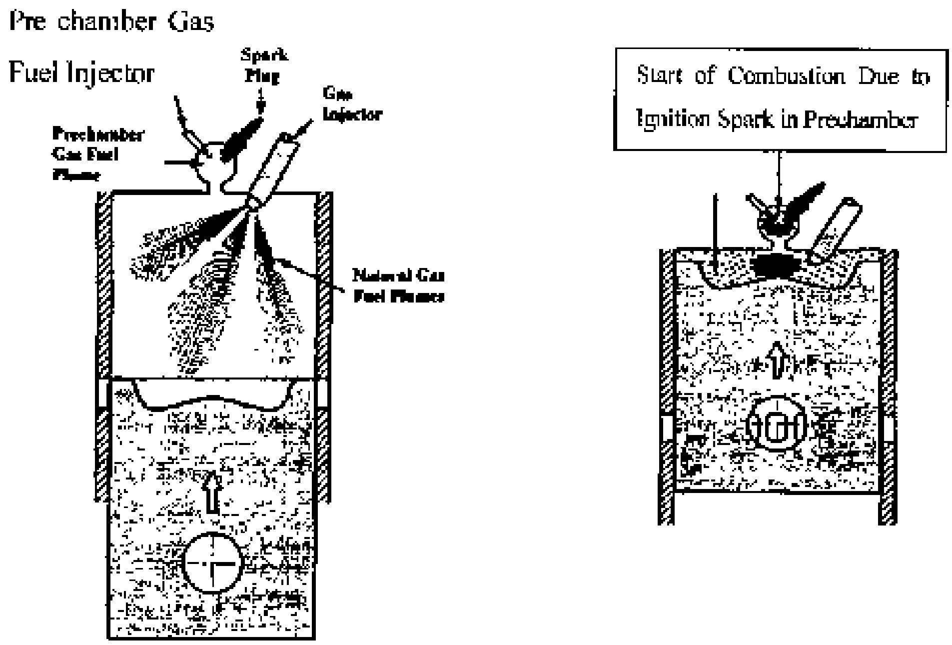


Figure 10: Pre-Chamber Spark-Ignited Setup

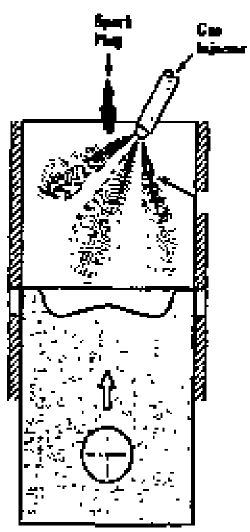


Figure 11: Spark-Ignited Open-Chamber Combustion System

4.2.2: Dual fuel combustion system

In dual fuel combustion system, a conventional diesel engine can be operated on a combination of NG and diesel fuel. Using this system, NG is either added into the intake air stream or directly injected into the combustion chamber. A minute amount of diesel fuel is then injected into the combustion chamber through a standard diesel injector. The diesel fuel acts as an ignition source. When NG is added to the air stream, some of the fuel-air mixture will go directly into the exhaust, increasing the fuel consumption and hydrocarbon emissions. This is particularly significant in a two-stroke engine during the scavenging process. Therefore, only those systems in which NG is directly injected into the combustion chamber are considered potential candidates for locomotive engines.

Pilot diesel injection provides a reliable mode of ignition compared to conventional spark ignition, particularly for very lean mixtures of methane and air. As mentioned previously, precise control of spark timing is crucial in spark ignition engines. With pilot diesel ignition, precise injection timing is not critical and there is less cycle-to-cycle variation, resulting in smoother operation. The engines are un-throttled, which reduces the fuel consumption; however, at light loads the fuel/air ratio becomes very lean, resulting in poor combustion. Hence, at very low loads the engine will be required to operate on 100 percent diesel fuel. Finally, retaining the diesel fuel system allows an engine to continue operation if a failure occurs in the NG supply.

a) Low-Pressure Early-Cycle Injection

In this system, NG is injected into the combustion chamber early in the intake cycle. In a four-stroke engine, gas injection occurs when the intake valves are closed, while for the two-stroke engine this take place right after the intake ports are closed. Since NG is injected at low pressure (approximately 120 psi), lightweight tubing, fitting, and couplings can be used. On the other hand, the early injection causes the engine to be sensitive to gas composition and may require high-purity NG for engine operation. Sensitivity to fuel composition occurs if the mixture is outside the flammability limits but still ignites irregularly. Care must be exercised during the development process to ensure adequate compression ratio, combustion chamber design, and amount of intake swirl.

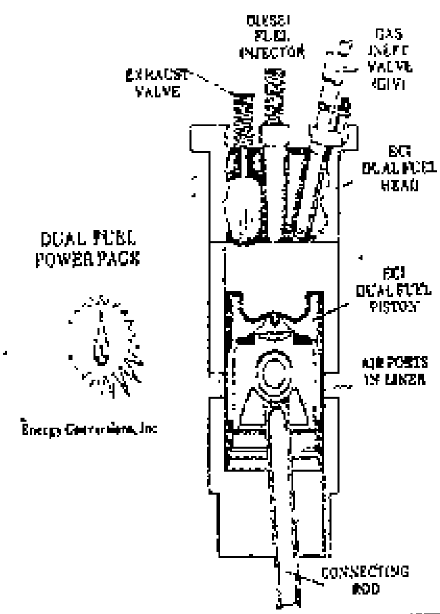


Figure 12: Low-Pressure Early-Cycle Injection System

BN started their experiments with NG fuelled locomotives in 1983. In that year, BN modified an EMD model GP-91 locomotive, powered by a 16-cylinder, 1300 kW, model 567C engine to run on NG (dual fuel) [6]. A CNG highway trailer mounted on a flat car was used to fuel the engine. On-the-rail tests conducted between 1985 and 1987 proved that an NG powered locomotive could be operated safely. This experience also illustrated that the relatively low-energy density of CNG makes it impractical for wide-scale railway use, explaining why BN's focus shifted to LNG.

In 1995, BN merged with the Atchison, Topeka and Santa Fe Railway Company to become Burlington Northern Santa Fe Railway (BNSF). The new management decided to terminate their experiments with SD40-2 dual-fuelled locomotives. At the time this decision was made, new microprocessor-controlled locomotives were introduced by both EMD and GE. These units offered dramatic improvements in power, adhesion, reliability, and fuel consumption, compared to that of SD 40-2 units. BN's extensive experience with dual-fuelled locomotives clearly demonstrates the reliability, durability, and safety of natural gas fuelled locomotives. The ease of operation and performance compared to their diesel counterparts were witnessed and acknowledged by those who had the opportunity to operate them.

b) Late-Cycle High Injection Pressure

Late injection of NG into the compression portion of the cycle requires high pressure (normally about 3000 psi). High pressure is required to overcome compression pressure and to provide adequate fuel-air mixing. This system makes the engine less sensitive to explosion and changes in gas composition, but necessitates stronger tubing, fittings, and couplings in the NG part of the fuel system. It also requires a high-pressure pump. Since the system uses high-pressure gas injection, the safety issue is the main concern. Any leakage in the fuel system can have catastrophic consequences. Since 1986, SwRI has been actively involved in development of such a system for railway applications.

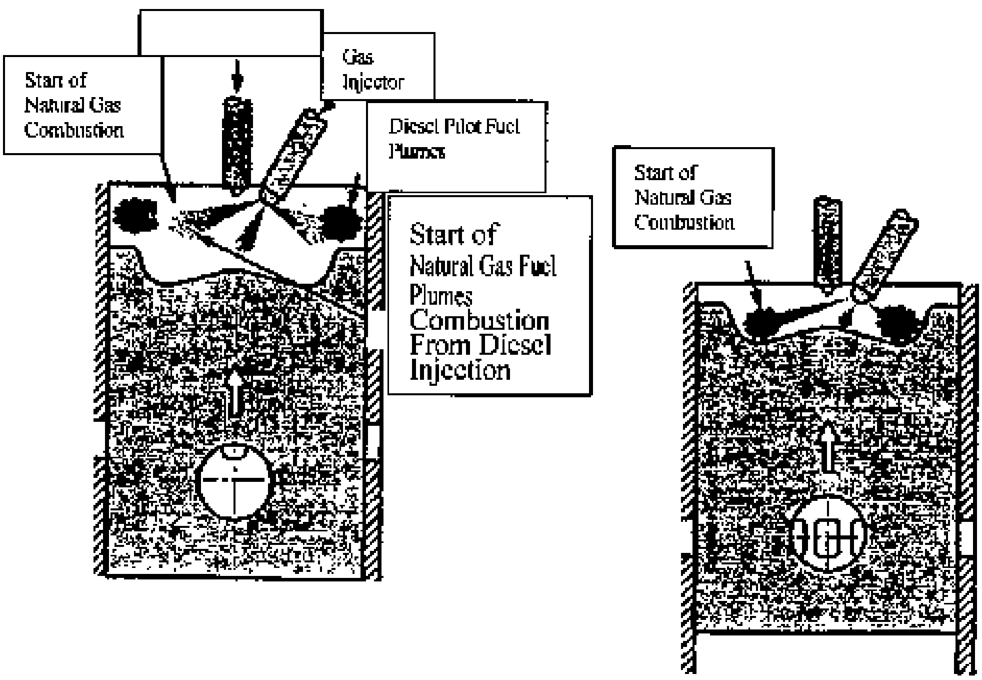


Figure 13: Combustion System of Late-Cycle High Injection Pressure

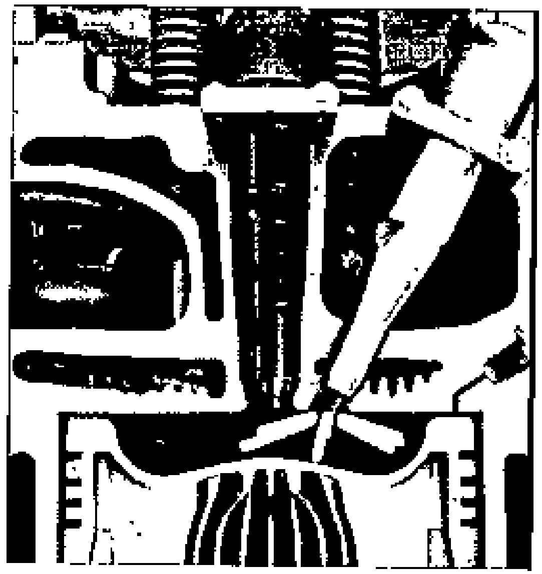


Figure 14: Cutaway of Late cycle Combustion System

In 1986, a model 567B two-cylinder research engine manufactured by the Electro-motive Division (EMD) of the General Motors Corporation was modified for dual fuel operation using NG as the primary fuel and diesel fuel as pilot charge to ignite the gas. The project illustrated that high-pressure, late-cycle gas injection can produce engine performance that matched that of regular diesel engine with slightly lower thermal efficiency [6].

In 1993, SwRI initiated a collaborative industry research program to develop NG engine technology for U.S. railway passenger and freight locomotives and to illustrate that the use of NG can produce lower exhaust emissions. This research program was based on the earlier work performed in 1986. The latest version of the combustion system named LaCHIP was a modified model of the earlier design with an enhanced injector system and a new piston head design. According to SwRI, the new injector and piston head design can achieve 75% NOx reduction with low CO and THC emissions.

4.3: Conversion System

This section describes the equipment and the operation of a system used to convert an EMD diesel locomotive engine to operate using natural gas as a major energy source. The retrofit system developed uses electronic controls, sensors and actuators to monitor system variables and perform the required control functions of the dual fuel locomotive engine. Among the required controls are gas injection timing and rate, the control of the diesel pilot level, turbocharger waste gate and a device that causes the engine to operate alternately on half of its cylinders during times of low specific power output. Along with the addition of controls, changes were made to the design of the pistons. cylinder heads and engine air cooling.

4.3.1: Technical aspects required

Burlington Northern Railroad's (BN's) efforts also brought into focus several issues that needed to be addressed before natural gas locomotion would be truly practical. For the development discussed in this work, BN stipulated the following requirements [8]:

1. Natural gas capability must be provided by a means of conversion or adaptation of existing high-power locomotives;

2. The converted engine must be capable of operating on 100% diesel fuel;

3. The converted engine must be able to withstand locomotive duty cycles;

4. The converted engine must produce not less than 90% diesel-rated power;

5. The engine must not lose any thermal efficiency; or, if it can produce 100% diesel-rated power, then it must not lose more than 10% thermal efficiency.

Using these guidelines, ECI developed a conversion system for a General Motors EMD 645E3 locomotive engine. This engine is a 45°–V, two-stroke, turbocharged, medium speed diesel, with cylinder configurations of 8.

4.3.2: System overview

The converted engine is equipped with new electronic engine controls, sensors and actuators. Newly designed pistons, cylinder heads and charge air coolers replace the originals. With the conversion installed, the engine starts and idles on diesel. It retains the ability to operate on full diesel, with critical components such as the engine governor and fuel injectors remaining virtually unchanged. Under normal circumstances, when the engine throttle handle is placed in notch 3, dual fuel operation automatically takes place. Engine speed is controlled by varying the gas flow to a pressure-timed fuel delivery system. Gas fuel is delivered directly to the combustion chamber early in the compression stroke. Combustion is initiated by injecting a small amount of diesel near top dead center of the compression stroke [9].

4.3.3: Transient response

In dual fuel operation, a gaseous fuel is mixed with air and the mixture is inducted into the engine. The temperature and pressure prevailing at the end of the compression stroke, a small amount of diesel oil is injected into the engine using a conventional injection pump and injector system. This small amount of diesel oil, hereinafter referred to as pilot fuel, ignites and consequently ignites the gas/air mixture so that combustion thereof takes place.

It is desirable to inject the minimum amount of pilot fuel in order to minimise the proportion of diesel fuel used since diesel fuel is more expensive than gas. Practical experience shows that a suitable ratio at full throttle operation for a typical automotive diesel which it is desired to convert to operate on gas is around 10% diesel oil and 90% gas in terms of the energy provided by the respective fuels.

The injection of the required amount of pilot fuel is achieved by positioning a control member, conventionally referred to as the rack. It has been found that if the control member is maintained in a fixed position to give the desired amount of pilot fuel at full throttle operation, the amount of pilot fuel injected per stroke of the engine increases significantly, and sometimes very substantially, with engine speed. The position at which movement of the control member of the pump is arrested can be determined, not only on the basis of engine speed, but also by other operating conditions such as the position of the speed control (i.e. throttle) of the engine, alone or in combination with the engine speed.

However, increasing the compression ratio also increases the visible smoke emissions at partial engine loading. The problem of visible smoke is especially acute during transient load and speed changes, i.e., when the locomotive operator advances the throttle (i.e., moves the throttle to a higher notch position) to call for higher speed and/or greater load pulling capacity (i.e., locomotive horsepower). A locomotive typically has 8 discrete notch settings called "notches".

A system is needed for controlling locomotive smoke emissions and noise during transient operation wherein the locomotive comprises a throttle drivingly coupled to a diesel engine, and wherein an operator of the locomotive changes a throttle position as required during operation of the locomotive. The locomotive has a locomotive controller for generating and sending a signal in response to a change in the throttle position, and one or more fuel pressure sensors for detecting a fuel pressure within the accumulator and sending the one or more signals relative such fuel pressure. In addition a fuel injection controller is in communication with the locomotive controller, the fuel pressure sensors, the one or more of the fuel injectors. The fuel injection controller in response to signals received from the locomotive controller and the fuel pressure sensors generates one or more signals relative to a fuel injection strategy during the transient operation and responsive to which a valve in the injector opens or closes and responsive to which a high pressure fuel pump increases or decreases the pressure level the fuel injection system. In addition, or alternatively, the fuel injection controller may transmit a signal indicative of a plurality of injections in a single engine cycle during the transient operation to reduce the noise emanating from the engine.

4.3.4: System component

Following system component is needed for conversion:

a. Gas Inlet Valves
b. Cylinder Head
c. Piston
d. Electronic controls
e. Wastegate
f. Pilot Fuel
g. Conversion kit
h. Bank Idling component

i. Charge Air Cooling component

a. Gas Inlet Valves

The gas fuel cannot be introduced and mixed with the engine's air inlet because a significant amount of this air escapes from the engine during exhaust scavenging. Gas must be injected directly into the combustion chamber after exhaust valves have closed. If the engine isn't running on gas most of the time, the mechanical valves will cause problems. For example, the mechanical valves are operating constantly, even when the engine is running under 100% diesel. The design of the mechanical valve allows lube oil to pass along the valve stem past the valve guide into the gas admission chamber. When the engine is off gas, the backpressure that normally inhibits the passage of oil is not present. The valve lube oil that gets past the guides is then blown into the gas headers by the aspiration of the engine. These and other difficulties promoted the design effort on the gas inlet valve. The gas inlet valve fits into the cylinder head much like a diesel injector. Its purpose is to control the timing of gas delivery to the combustion chamber and to hold back the pressure of combustion. Its basic design involves a spring return poppet valve with appropriate valve guides and housing so gas can be channeled to the combustion chamber when the valve is opened. The gas inlet valve uses an electric solenoid valve to control compressed air. When energized the solenoid valve allows air pressure to act on a small piston that is attached to the stem of the poppet valve. The air pressure on the surface of the piston compresses the valve spring and the valve opens. The gas inlet valve is therefore electronically controlled, pneumatically actuated. Electronic control allows the valves to be left closed during non-gas operating modes. Timing and duration of valve opening is controlled by the electronic control unit. The gas pressure required for the system is 5.9–8.6 bar (85–125 psig). The required injection pressure (gas pressure down stream of the flow control valve) is both speed- and load-dependent [9].

b. Cylinder Head

To inject gas to the combustion chamber, the cylinder head has been manufactured with an additional port that accepts the gas inlet valve. Apart from the gas inlet valve port and a cutout for gas inlet valve clearance, the cylinder head is unchanged, retaining standard exhaust valves and other components.

Fig 15: ECI dual fuel head with electronic gas injector installed

c. Piston

The piston design is modified to reduce the compression ratio and promote turbulence. During development, piston designs were tested with the use of a two piece test piston, allowing a number of crown designs to be evaluated. A reentrant type of design provided increased power capacity due to the better mixing of air and fuel. The ECI piston provides optimum combustion in the dual fuel engine.

Fig 16: ECI's Dual Fuel piston on the right.

d. Electronic controls

Electronic controls are employed to provide the flexibility, performance, and automation required by a locomotive engine application. The electronic control unit is an enclosure that contains two microprocessor-based control boards, signal conditioning, isolation and interconnecting hardware. External to the electronic control unit is a power supply assembly, power supply transient filter and additional signal conditioning modules.

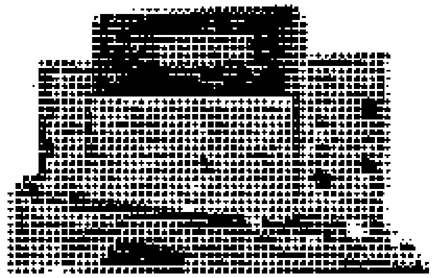


Fig 17: ECI's sophisticated engine control unit (ECU)

The "valve sequencer" is one of these control boards. This board has been designed specifically for timing control of the gas inlet valves. Two sensors generate electrical pulse information from targets located on the flywheel. The signal timing provides information the valve sequencer needs to determine when and for how long the gas inlet valves should be energized. These signals are evaluated to insure that they occur when expected and that control functions are not being carried out using faulty information. The valve sequence receives a discrete signal from the main control board telling it to operate. The valve sequencer in turn responds by returning a status signal indicating that it is operational. The control signals from the valve sequencer are sent to a solenoid driver board. This board contains fuel injection driver chips that hit the solenoid valves with full voltage until the current reaches a 4A peak and then reduces the current to a holding level of 1A. This creates a high response valve without excessive heat buildup in the valve coil. The main control processor is a 16-bit board running at 10 MHz with 12-bit analog-to-digital conversion. This board processes analog signals representing engine speed, load, temperatures and pressures. It also processes digital input signals representing the position of the throttle handle, load control contactors, valve sequencer status, power supply status and operator input. Once the controller has determined that all of the necessary prerequisites have been met, gas operation commences. The controller uses two analog outputs to control the speed of the engine, and the load placed on the generator, when on gas. Digital outputs control the diesel's governor, pilot fuel level and waste gate. Speed control accomplished by a modified PID algorithm that ramp to the new values for speed set point and integral when the throttle position is changed. The engine load control signal is generated by another PID loop based on predetermined set points and the rate of gas fuel flow. The load control signal turns on a simple transistor circuit that shunts some of the power from the existing load control to ground.

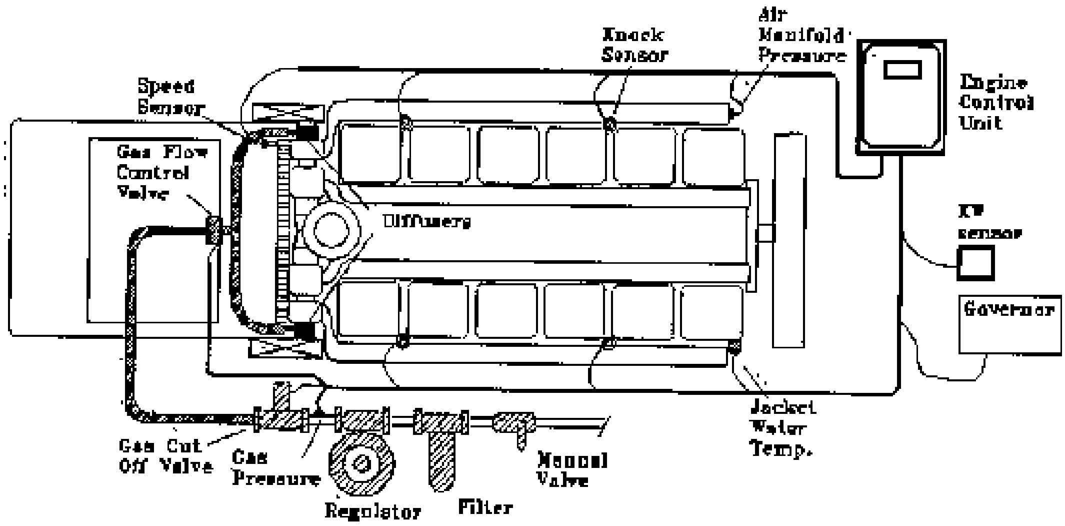


Fig 18: Natural gas delivery system

e. Wastegate

The level of excess air required for combustion of the natural gas along with the reduced efficiency of the combustion event created the need for a turbocharger wastegate. The flow paths of the EMD turbocharger, like other medium speed V–configured diesel engines, has two air paths and only one exhaust path. For this reason we chose to install the controlling valve on the exhaust side of the system. The waste gate allows exhaust gas to bypass the turbine. The dual fuel engine is very tolerant to varying air/fuel ratios, but wastegating some of the exhaust energy not only reduces the turbine speed but increases the fuel efficiency of the engine as well. The wastegate is a very simple gate-type valve whose operation is either fully open or fully closed. In the open position the flow of the exhaust bypassing the turbine is controlled by an orifice plate. The wastegate is opened when the boost pressure from the turbo exceeds a predetermined level.

f. Pilot Fuel

Due to the changes in engine speed and load, the pilot fuel control is not as simple as providing a single stop position for the diesel fuel racks. The rack position must be adjusted as the engine speed increases to maintain minimum pilot fuel. To perform this task, three air cylinders are mounted together such that they provide a linear motion that increases with the number of cylinders having air applied to them. As speed increases, the air pressure is relieved from the cylinders in sequence and the pilot setting decreases accordingly. The diesel injectors are altered only in the way that they are calibrated. Calibration of the injectors is done at the pilot fuel rack setting 1.880" instead of the normal 0.780" rack setting.

g. Conversion kit

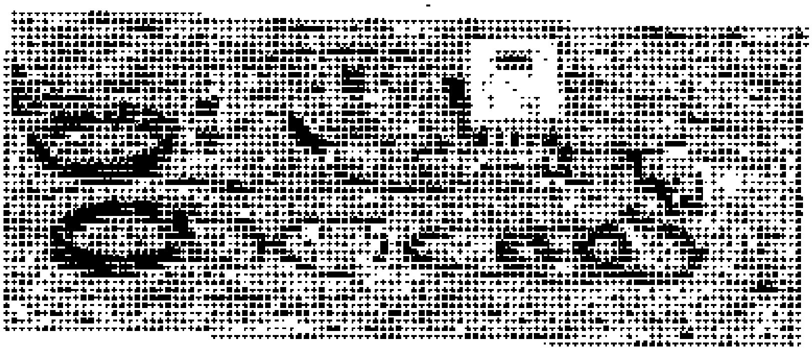


Fig 19: conversion kit

Conversion kit contains the followings [10]:

Table 8: Conversion kit list

Gas Supply	1. Shut off valve 2.Gas Filter 3. Pressure regulator 4. Automated shut off valve 5. Gas flow control valve 6. Diffuser 7. Connecting fittings and hose
Sensors	1. Boost pressure 2. Gas pressure 3. Barometer 4. Speed 5. Kilowatts 6. Governor Position 7. Water temperature 8. Exhaust Gas temp. 9. Knock / vibration 10. Wires and connectors
Electronic	1. Control system 2. Control computer 3. Analog module 4. System information screen 5. Amplifier 6. Knock detection filter 7. Power module 8. Power relays 9. Driver module 10. Terminals, wire connections

h. Bank Idling

The operating duty cycle of a locomotive changes with the train and route that they are assigned to; however, typical operation shows that a locomotive spends more than 40% of the time in idle. Idle speed ranges from 250–300 RPM to 500 RPM in low ambient temperatures. Low load, low speed operation along with the reduced compression ratio of the dual fuel piston results in less than optimum diesel combustion. To curb smoke and reduce fuel consumption at idle and low load conditions, bank idling is employed. Bank idling reduces the number of cylinders that are producing power by reducing the fuel rack of one bank of cylinders to a no-fuel position. This increases the work that the remaining cylinders must do. The increased work causes combustion to be cleaner and more efficient. To implement bank idling we designed linkages that are spring loaded to the normal fuel position. When the controller determines that low load condition exists, air pressure is applied to one of the two linkages. The air compresses the spring and the linkage floats to the no-fuel position. After a period of time the air pressure is switched to the opposite linkage and the engine then operates on the opposite bank of cylinders. The cycling is maintained during idle, keeping both banks warm and relatively clean.

i. Charge Air Cooling

In all turbocharged diesel locomotives, some sort of heat exchanger is used to control the temperature of the air exiting the turbocharger. At high loads the intake air temperature is reduced, which in turn enhances the engine's efficiency. EMD turbocharged engines use engine jacket water in their charge air after coolers. On locomotives this jacket water serves two purposes. At low speed and load these heat exchangers work to increase the air temperature, enhancing the diesel combustion quality. At high speeds and loads, the heat exchangers reduce the air temperature, allowing more air to enter the combustion chamber. On the dual fuel engine air temperatures play a strong role in the level of power that can be produced before knock occurs. To achieve diesel-rated power, enhanced aftercooling of charge air is required. The converted locomotive is equipped with additional radiators. Water is circulated and cooled from these radiators and directed to the aftercoolers. Thus the air from the turbocharger is cooled to a greater extent than with the standard cooling configuration and higher power is achieved. In the case of low engine speed and load, the water flow is no longer taken from these radiators, but instead from the outlet of the engine. The engine water is then directed into the aftercoolers and thus heating the air for good combustion.

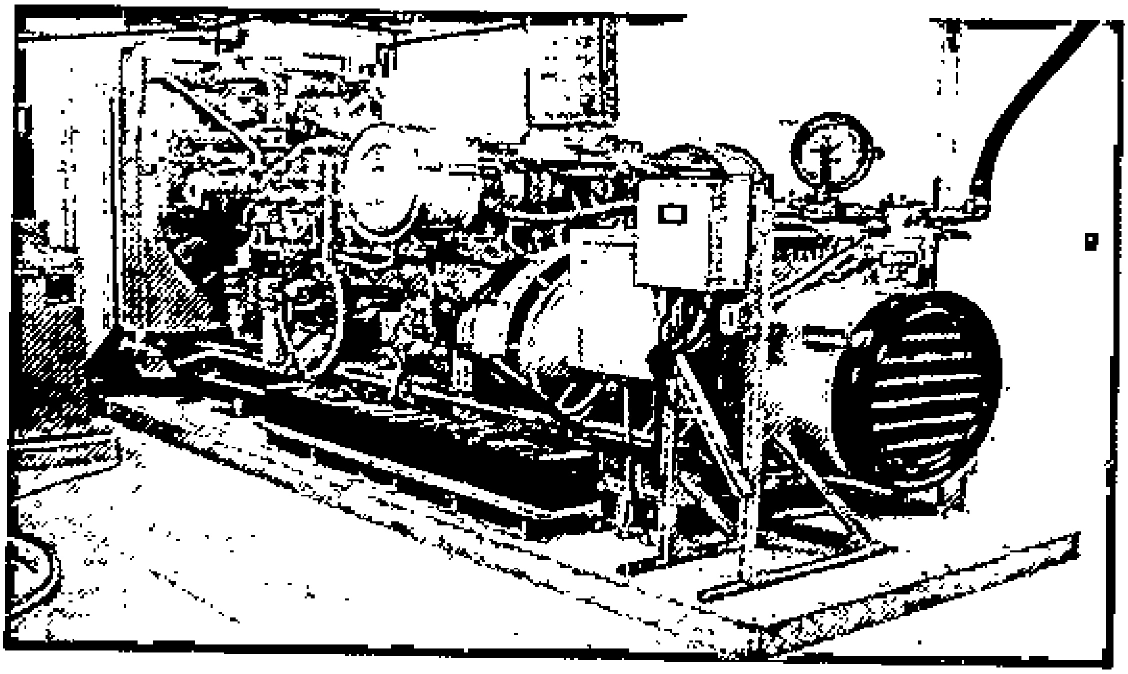


Fig 20: Dual fuel converted Locomotive Engine

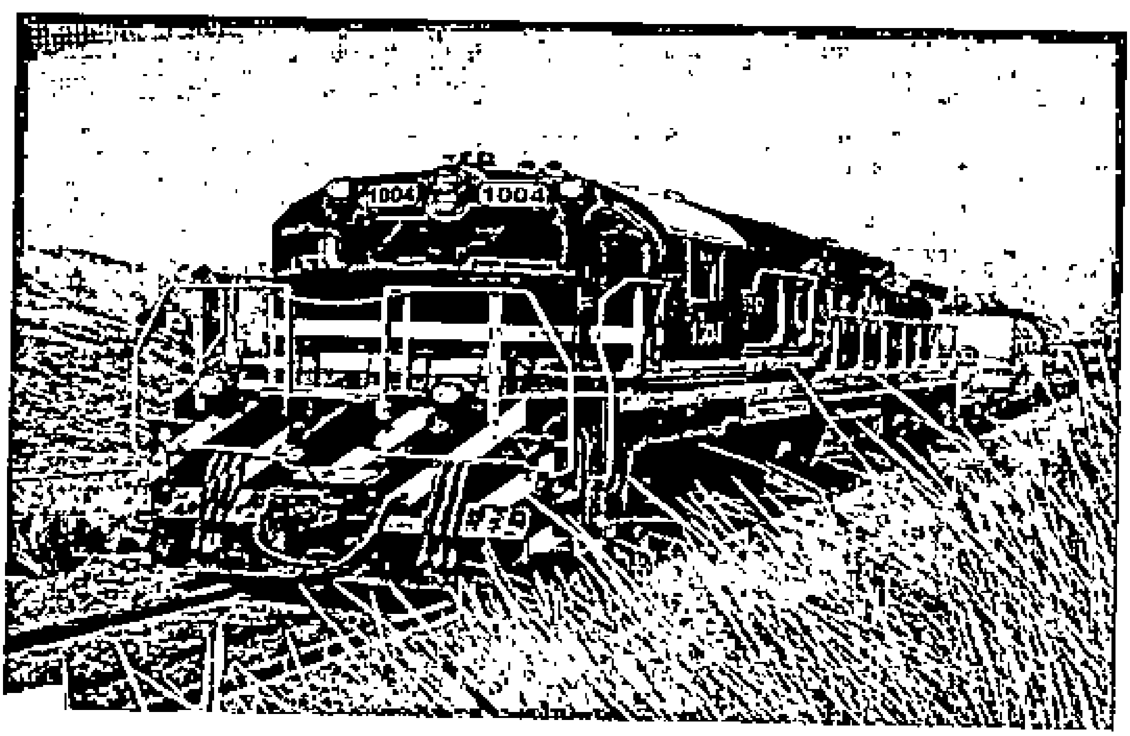


Fig 21: NG fueled Locomotive in Peru

4.4: Recommended Conversion System for BR

In the light of the available reports discussed in the previous sections, the dual fuel combustion system seems to be suitable for Bangladesh Railway. There are a few points in favor of the low-pressure early cycle of dual fuel system as follows:

1. Dual fuel engine can also operate using 100% diesel fuel in absence of natural gas or any problem of gas injection system. As a new user of natural gas fueled locomotive, BR may face some problem of gas system. That time locomotive could run by using diesel. In other system it would not be possible.

2. Spark plug in combustion of high compression ratio is very new and it is not familiar to BR. On the other hand, diesel injector is very familiar to BR which will give more confidence in maintenance of dual fuel engine. From that point, BR should prefer dual fuel system to gas mixing system.

3. Compare to other system, less investment and modification is needed to convert dual fuel locomotive from existing diesel locomotive.

4. In case of high-pressure late cycle injection, the safety issue is the main concern. Form the viewpoint of safety; low-pressure early cycle injection system is preferable.

4.5: Considered items to convert Locomotive of BR

There are some important factors that should be considered to start natural gas or duel fuel locomotive. In this chapter, those factors and opportunities to fulfill the considered factors would be discussed. The considered factors are as bellows:

1. Engine
2. Infrastructure
    a. CNG filling station or LNG production plant
    b. CNG / LNG storage system and delivery system
    c. CNG / LNG on-board storage system
3. Natural Gas quality

a. Desired fuel quality

b. Bangladesh Gas quality

c. Combustion characteristics

4. Availability of NG in Bangladesh

4.5.1: Engine

A critical decision in the design of a natural gas-fueled railway operation is the choice of engine or prime mover, installed in the locomotive. NG powered locomotives are classified as either freshly manufactured or rebuilt, that is, re-manufactured to original specifications following expiration of their useful life. For rebuilt locomotives, the only variance from conforming to original specifications is the installation of retrofit kits.

There are a variety of technical designs, specifications and arrangements of locomotives commonly used in Bangladesh railway. Most of the locomotives used in Bangladesh Railway are very old. There exists capability in Bangladesh to rebuild to original specifications of locomotive. It would appear that, from a cost viewpoint, use of rebuilt locomotive would be the preferable option. A drawback for some service applications of rebuilt locomotives is that the lack of modern electronics systems that provide improved control, adhesion and monitoring capabilities.

Engines used in Bangladesh railway service are classified as either GM (General Motors) or ALCO (American Locomotive Company). The dominant companies that have supplied and continue to supply medium-speed diesel engines for the Bangladesh railways are the two U.S. based GM EMD and ALCO. Energy conversion inc., USA, has given conversion specifications for GM EMD 645 turbocharged duel fuel engine which is given in appendix-2 of this report. Bangladesh Railway owns some locomotive of the same type, which could be converted to duel fuel engine.

4.5.2: Infrastructure

Following infrastructure is required to CNG / LNG powered train:

a. CNG filling station or LNG production plant

b. CNG / LNG storage system and delivery system

c. CNG / LNG on-board storage system

a. CNG filling station or LNG production plant:

The technical and financial feasibility of CNG project stimulated to form a CNG company named 'Green Filling Station Company' in 1987. This company later on renamed as Rupantarita Prakritik Gas Company Limited (RPGCL) in 1991 to expand its business including processing of NGL.

The Government adopted some policies for expansion of CNG activities. The major policies are as follows:

a) Allocation of government land to private investor for CNG purpose
b) Duty free import of CNG equipment and machinery
c) Advance income tax free facility for CNG equipment and machinery
d) Five to seven years tax holiday
e) Restructure of gas tariff for CNG

There are around 200 CNG filling stations in Dhaka city under Titas Gas Transmission and Distribution Co. Ltd and total 240 CNG filling stations all over the country. Their capacity is 450 to 750 m3 / hr at 3000 psi. Establishment cost of CNG filling station is around 3, 00, 00,000 (3 crore). It will be viable if total sale of gas 1, 00000 tk / day [11]. Now, CNG price is 16.75 tk / m3.

On the other hand, there is no LNG plant in Bangladesh. It is very new and unknown technology in Bangladesh. According to RPGCL (A company of petrobangla) personnel, LNG production plant would be financially viable if it can sell LNG of Tk 2 billions.

b. CNG / LNG storage system and delivery system

For an envisaged demonstration, it is judged more feasible for the natural gas to be purchased from a vendor and delivered either directly to the train consist or into a rail yard storage tank for subsequent dispensing by railway crews. The gas can be delivered either at pipeline pressure or as CNG or LNG.

Depending on the operational schedule, natural gas in the LNG / CNG state can be dispensed either directly to the tender consist in train by a local vendor, or from specially insulated rail yard storage tanks. Awareness of the specific cryogenic characteristics of LNG would need to be emphasized with employees and detailed training programs instituted.

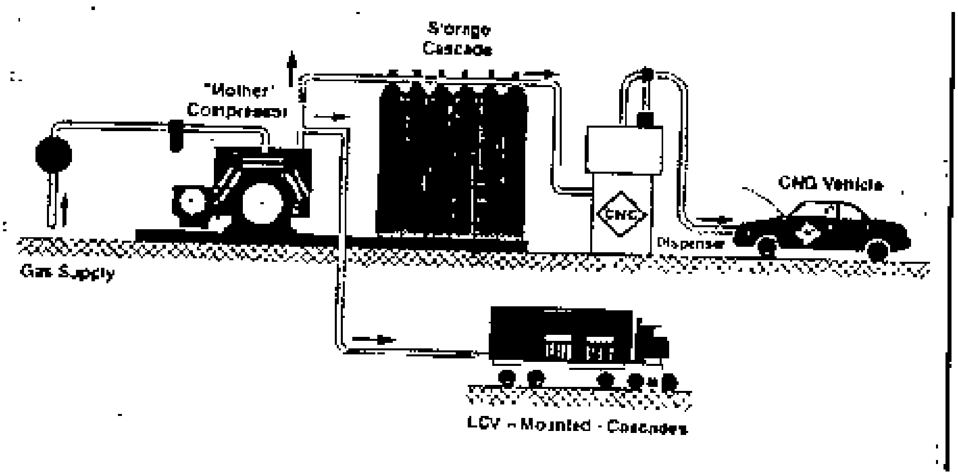
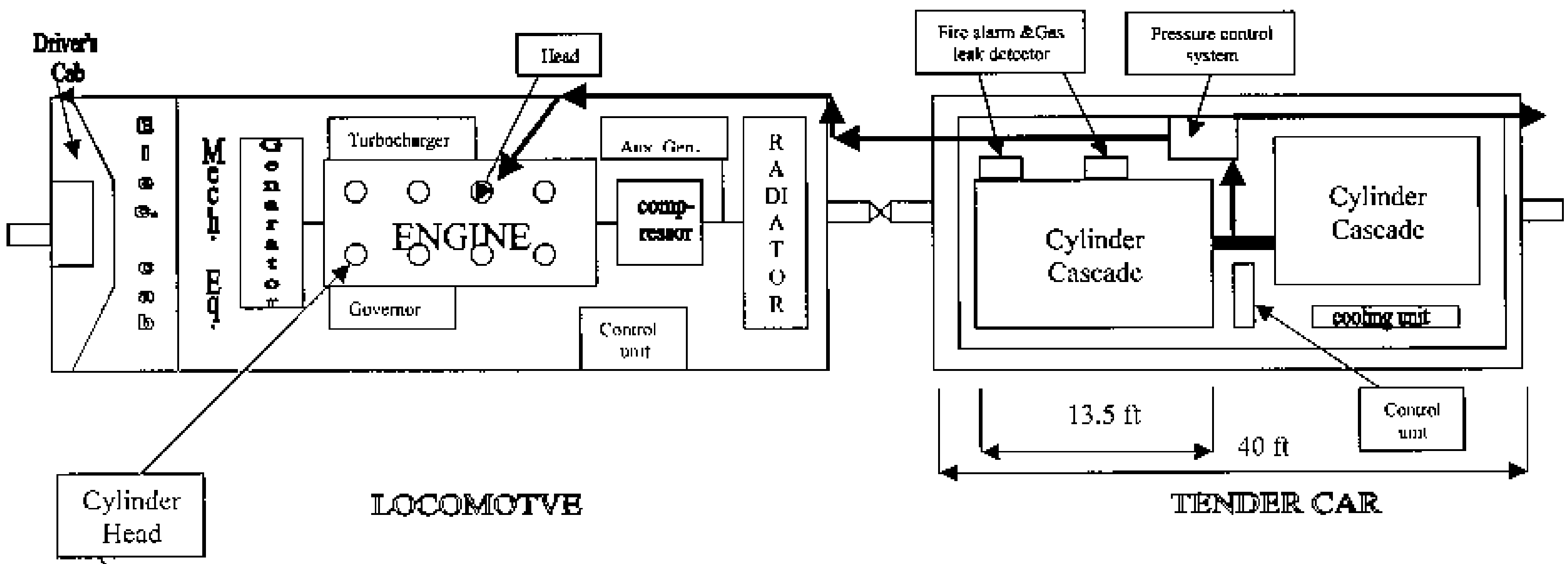


Fig 22: CNG fueling station

c. CNG / LNG on-board storage system

On-train storage of natural gas in would be via either CNG bottles or specially insulated LNG tanks. The LNG tanks can either be on-board the locomotive (or power car) in place of the existing diesel fuel tank or as a separate tender railcar closely coupled to the locomotive. The tender would have the appearance of a tank car but, in fact, would be quite sophisticated with multiple safety and protective devices, extensive piping and control systems for filling, venting and vaporizing the gas.



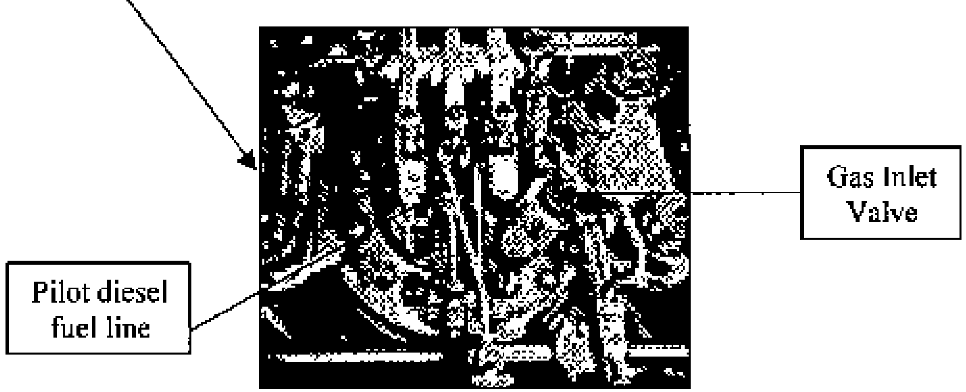


Fig 23: Schematic Diagram
Of
On-Board
CNG Supply System

On-Board Storage of LNG:

Fig 24: LNG tender car.

In order to keep natural gas in a liquid state, it must be refrigerated to -260 degrees Fahrenheit. To maintain such low temperatures the tender car is of a double walled stainless steel "thermos bottle" design, capable of keeping the LNG cold for as long as 14 days. A heat exchanger aboard the tender car converts the LNG back to a gaseous state. Gas then flows to the locomotive through flexible hose connection between the tender and the locomotive engine. No cryogenic fuel is ever transferred onboard the engine. Safety features built in to the coupling inhibit the release of gas in the event of train-tender disconnect.

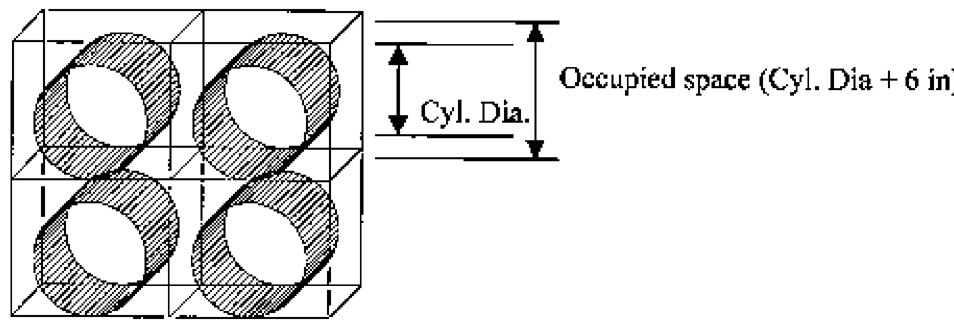
Based on the tender designed for the Burlington Northern Railroad demonstration, it would be constructed of a stainless steel inner tank shell surrounded by 15 cm of vacuum drawn insulation which, in turn, is encased in a carbon steel tank shell.

On-Board Storage of CNG:

The technology permits the storage of natural gas at high pressure (3000psi) in quantities sufficient for the operation of a railway locomotive over distance equal to liquid fuel ranges. The natural gas storage tanks are housed in a standard sized ISO intermodal shipping container structure. Size and weight of this type of storage cascade is 4000X1650X1600mm (13.5X5.5X5.25 ft) and 4500kg respectively. A standard container flat car carries one or two CNG transport fuel storage containers [12]. This assembly will contain enough gas for around 45-hour operation of a single locomotive.

Table 9: CNG Cascade Specifications

SL. No	Options	No of cylinder (Water capacity)	Dia. (in)	Length (in)	Capacity / Cylinder (cu. meter)	Weight / Cylinder (kg)	Weight of Cascade (kg)	Weight of Gas (kg)	Total weight (kg)	Total volume occupied (cubic ft)
1.	Cascade of Cylinder	50 (50WL)	9.13	40	12.5	58	2900	438	3338	300
2	Cascade of Cylinder	50 (60WL)	11	49	15	60	3000	525	3525	450
3.	Cascade of Cylinder	100 (50WL)	9.13	40	12.5	58	5800	875	6675	600
4.	Cascade of Cylinder	200 (50WL)	9.13	40	12.5	58	11600	1750	13350	1200
5.	Cascade of ISO inter modal shipping container structure	48 (60WL)	9.13	60	18.75	-	4500	630	5130	400



Standard floor space of a flat container car is 40 ft X 8 ft with carrying capacity of 30 ton. Due to Bangladesh Railway height restrictions, it can carry up to 8 ft height container. Fabrication of double walled GI protection with mineral wool / glass wool packing is needed around CNG cascade for isolating CNG storage area. Remaining space after building protection wall would be 38ft X 6ft X 6ft. Control system, pressure reducing valves, piping, cooling system and other auxiliaries would occupy some space (10ftX6ft). Two CNG cascade (13.5 X 5.5 X 5.25 ft) with necessary controls, valves, safety systems, etc can be connected in series in order to increase storage capacity. Among all cascade options (Table: 23), it occupies less space on flatcar and easy for operation & maintenance. The CNG cascade used confirm to following specifications:

Capacity: 48 nos X 60 WL (900 cubic meter of gas)

Water capacity: 60 litres

Number of cylinder: 48 nos

Outer diameter: 232 mm (9.13 in)

Wall thickness of cylinder: 7.0 mm

Length: 1515 mm (60 in)

Steel grade: Seamless Chrome Molybdenum Steel

Working pressure: 200 bar

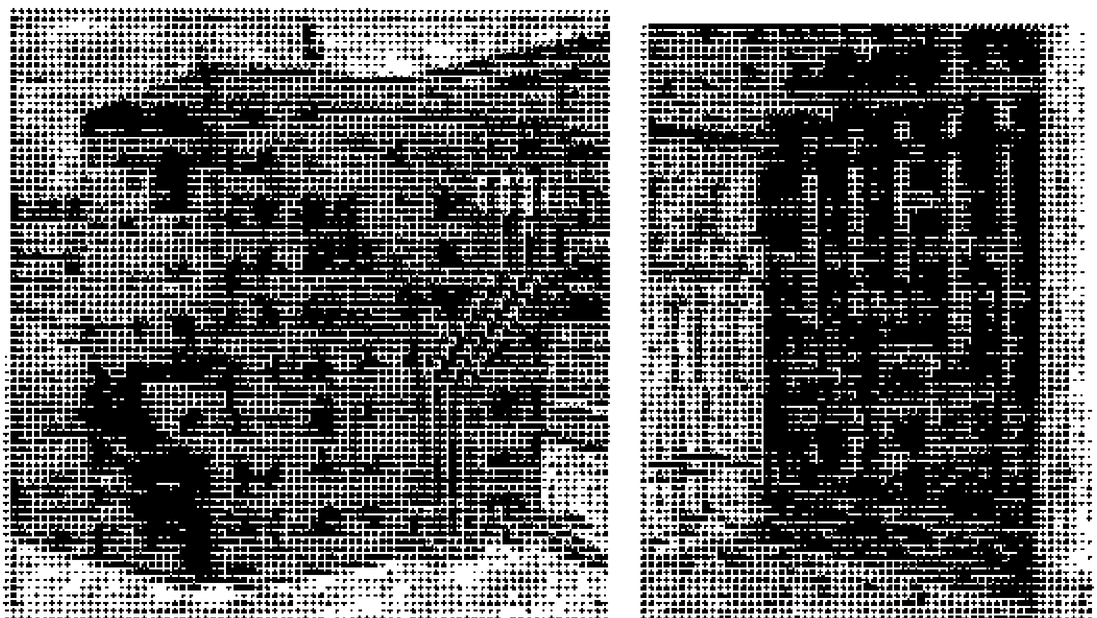


Fig 25: GNG storage bottle cascade

For dual fuel engine, the consumption of CNG is 40 CUM per hour; hence for twenty hours of uninterrupted operation, a total of 800 CUM of natural gas will be required. A cascade of 48 cylinders each with capacity of 14 Kg can store the required amount of 560 Kg of CNG, which comes to more than 900 CUM at a density of 0.7 Kg. /CUM [12]. A tender car could be store 1800 CUM gas. Total weight of CNG tender car would be (4500kg for cascade + 560kg for gas) X 2 nos = 10.2 ton which is below the allowable carrying capacity.

Fig 26: Close up of the tender / locomotive connection

The CNG transport fuel storage container car or purpose designed railcar would be pulled directly behind the locomotive. Flexible low-pressure piping connects this car to the locomotive for supply of fuel to the locomotive. Pressure regulating valves and a simple PLC based control and safety system are housed in each of the fuel storage containers or railcars. Cylinders in cascade are firmly secured in their position to prevent any movement during run. Each container assembly is a self-contained locomotive fuel supply unit. Container cars could be shunted to a regional container refilling facility and then distributed to trains at each station location.

Recommendation of using CNG OR LNG:

Typically for locomotives, the preferred natural gas medium is liquid natural gas (LNG). Due to its density, five times more LNG can be stored in the same size container than compressed natural gas (CNG), saving valuable space and making refueling less frequent.

There are certain applications however which CNG may be preferable. Switch locomotives for one usually remain close to a station, and can be refilled easily during long idle periods. Commuter rails may also favor CNG due to their frequent and routine stops, and their typically close proximity to available gas supply.

In Bangladesh, there is no LNG production plant. From experienced it has been seen LNG production plant would be financially viable if it can sell LNG of Tk 2 billions. But in Bangladesh LNG selling market is very limited. So, it is not possible to build a LNG plant. On the other hand, CNG is more familiar to us. CNG filling station is very simple. CNG is available in all rail junction or Loco shed of eastern region of BR like Dhaka. chittagong, Akhaura, sylhet, Mymensing and Bogra.

Establishment cost of CNG filling station is around 3, 00, 00,000 (3 crore) [11]. From experience, it is found that Establishment of CNG filling station will be viable if total sale of gas 1, 00000 tk / day. Now, CNG price is 16.75 tk / m3 at STB. One tender car contains 900 CUM gas. Cost of 900 CUM gas 15,000 tk. So, Establish of CNG filling station will not be viable. It is better to buy gas from private CNG filling station.

4.5.3: Natural Gas quality

Natural gas is composed principally of methane (CH4), with smaller quantities of other hydrocarbons, carbon dioxide, and water. A typical breakdown of pipeline natural gas is given in the table 9 [13]. The non–methane hydrocarbons are known as "heavies"; multiple carbon atoms in their molecules give added molecular weight. The added carbon atoms also provide more available energy within their additional atomic bonds with hydrogen atoms. The heavies, therefore, contribute more BTUs (British Thermal Units) per volume of gas than pure methane would alone. Gas whose composition of methane and heavies results in a BTU content of over 1100 BTU per standard cubic foot (SCF) is known as "hot gas". Hotter gas is not necessarily better gas for engine use.

Table 10: Characteristics of pipeline natural gas

Component	**Molar%**
Nitrogen	0.323

Carbon Dioxide	0.174
Methane	92.241
Ethane	6.500
Propane	0.551
Iso Butane	0.042
N Butane	0.055
Hexanes +	0.045
Oxygen	0.069
BTU / cu. ft (MJ/cu. M)	1071.00 (40)

Fuel Quality Requirements for CNG/LNG powered Locomotive according to ECI; USA:

The quality of the natural gas used to fuel an ECI converted engine, with respect to its percentage makeup of component gases, will directly affect the power, efficiency, emissions, and longevity of the engine. As a general rule, higher methane content results in higher fuel quality. Of the hydrocarbons listed below, Butane is the most common variable to adversely affect engine performance. Hexane is more destructive than Butane, but is seldom seen at levels high enough to cause concern. In any case, maintaining hydrocarbon levels at or below indicated target levels is necessary for achieving rated power performance. Acceptable levels (in Molar percentages) for various component gases are described below, with the sum of all non-methane hydrocarbons not to exceed 8% of the total fuel mixture.

Table 11: Fuel quality requirement for NG Locomotive

FUEL QUALITY REQUIREMENTS - NATURAL GAS	
Element	**Tolerance**
Methane (CH_4)	> 92%
NON- METHANE HYDROCARBONS (NMHC)	
Ethane	< 8%
Propane	< 5%
ISO & N Butane, Pentane,	

Hexane, Heptane, Decane, combined total	< 2%

An engine's full rated horsepower can be achieved and actually exceeded if the fuel mixture is equal to or better than the indicated tolerances. If percentage levels of elements other than methane are too high, and rated power is required, then a program must be implemented to scrub the fuel to desired levels.

Combustion Characteristics of Gas:

A high octane (130) fuel, methane exhibits ideal knock characteristics for typical spark–ignited engines. Unfortunately, the characteristics that make for a good fuel for spark ignited engines generally make the fuel less desirable for compression ignited engines, such as the high horsepower diesels we are discussing. Such fuels require an extremely high compression ratio, or the introduction of heat energy into the cylinder from an external source. The compression ratio required to enable methane to compression ignite is too high to implement on these engines without seriously compromising engine reliability and performance. The solution adopted by the ECI system is to use a small amount of diesel oil as a pilot charge to initiate combustion of the natural gas/air mixture. Near the bottom of the piston stroke, the natural gas charge is admitted to the cylinder via the gas inlet valve (GIV), after air is inducted through the air intake ports. The fuel is mixed with the air and compressed as the piston rises. Near the top of the stroke, the pilot fuel is injected. The diesel fuel, with its lower ignition temperature, ignites, igniting the gas mixture along with it. This approach requires a lower compression ratio than standard, to avoid engine knock. As the combustion proceeds from the diesel injection, pressures spike within the combustion chamber. If pressures become too great, combustion can be triggered within the unburnt gas mixture ahead of the original flame front. This so-called auto-ignition causes destructive knock. A lower compression ratio generally spells lower efficiency. ECI's specially designed piston crowns and cylinder heads minimize this loss and allow for full diesel–rated horsepower in either dual fuel or diesel mode.

Characteristics of Natural gas available in Bangladesh:

Two samples are taken from different place and different period. Those are tested or break down in Bangladesh University of Engineering and Technology (BUET) laboratory. Break down results are given in appendix D & E of this report. These two samples fulfill the required characteristics of Natural Gas that used as Locomotive fuel. It can be concluded that combustion characteristics of Natural Gas available in Bangladesh will be very compatible for duel fuel Locomotive.

4.5.4: Availability of NG in Bangladesh

Natural Gas is the main natural resource of Bangladesh. Total remaining natural gas reserve of Bangladesh 12.043 TCF in developed reservoir. Including reserve of underdeveloped reservoir, total remaining natural gas reserve is 13.22 TCF. Cumulative production of natural gas up to end of 2007 is 7.37 TCF. In the fiscal year 2006-07, 562 BCF of gas have been used and among this only 4% gas used for CNG. Now, there are 229 CNG filling stations all over the country and those consume 47.86 MMCM gas per month. One CNG converted locomotive could be able to consume 40 CM gas per hour. If it would possible to convert 10 locomotive and those run 15 hour daily on average, total gas consumption would be 0.18MMCM per month which is negligible compare to total gas consumption. Moreover, CNG filling station is available in all rail junctions or Loco shed of eastern region of BR like Dhaka, Chittagong, Akhaura, sylhet, Mymensing [1].

4.6: Safety

The handling of natural gas is currently an unknown for the Bangladesh Railway sector. For this reason, the first concern to introduce natural gas powered train is safety. The law and order situation of Bangladesh is not good which should be mandatory to introduced CNG powered train, because any miscreant activity can easily happened which can be a cause of big accident. Although CNG is a flammable gas, it has a narrow flammability range that makes it an inherently safe fuel. CNG also disperses rapidly, minimizing ignition risk relative to air and will not pool as a liquid or vapor on the ground. In the event of a spill or accidental release, CNG poses no threat to land or water. CNG is primarily Methane, however, which is a greenhouse gas that could contribute to global climate change if leaked. Strict safety standards make CNG vehicles as safe as Diesel-powered vehicles. Dual fuel locomotives should be having following safety features to safeguard against fire in case of accident:

Pressure relief devices:

Pressure relief devices are provided to protect against the possible explosion of a CNG cylinder if it were involved in fire. They are designed to fail and release the cylinder contents before the cylinder walls rupture. They are incorporated with fusible elements that are designed to soften and release gas at predetermined temperature and prevent the chance of explosion even in worst possible scenario.

Flame Arrester:

It prevents any backward travel of flame in case of malfunctioning of valves in combustion chamber of engine.

Fire Alarm System:

It detects any smoke and fire through optical smoke detectors and will give fire alarm in the driver cab who can take necessary action to shutdown the engine.

Separate Storage:

CNG cylinders shall be stored in separate chamber, completely isolated from engine room. thus making the system free from fire hazard even in case of any leakage.

Gas leak detector:

Gas leak detector senses leakage of CNG inside storage area of CNG and gives signal to cut off the supply of CNG from cascade to the engine and thus prevents any consequential damage.

Anti Climbing Couplers:

Locomotives should be equipped with anti climbing couplers which will prevent the climbing of coaches over one another in case of accident, thus further minimizing the chance of fire due to collision.

Track Condition:

Track condition of BR is very poor in some area. On that type of track, excessive vibration can cause of disconnect coupling and fracture of gas cylinder. Due to bad track condition and single line, speed of train is low. As a result traffic density is very high. For that reason, sometimes train don't get path and it spend time in idle position or low speed. In idle position and low speed Duel Fuel engine consumes 100% diesel fuel. It should take initiative for repair of track.

Human factor:

Employees of BR are not familiar to NG powered train. They are familiar to diesel technology and their current practices. May be they would not want to switch from diesel to CNG. It is needed to motivate them in favor of NG technology.

CHAPTER 5

ECONOMIC ANALYSIS

For Bangladesh Railway, the greatest motivation to convert to natural gas is fuel cost saving. Some cost analysis projects were conducted in different countries to address this issue for NG fuelled locomotives, which are described in section 4.1 of this report. These reports only signify the fuel cost saving that can be realized by using NG fuelled locomotives. Use of NG as the primary fuel also yields cleaner lube oil and reduced engine wear. This will mean an extended useful life of the lube oil, fewer oil changes, and extended economic life of the engine, all of which result in a greater overall return per locomotive.

The given cost comparison does not include the impact of any environmental regulations on the cost of locomotive diesel engine since there is no such regulation in effect. As the air quality due to exhaust emissions deteriorates, it is foreseen that Bangladesh would adapt and implement an environmental regulation identical or similar to that enforced by the UNEP (United Nations Environment Program) of UN. In order to comply with such a regulation, new, rebuilt, and existing locomotive engines must be modified. Such modifications would drastically increase the cost of a diesel locomotive engine, making an NG fuelled locomotive even more profitable.

5.1: Financial Analysis

In this financial analysis, the following investment costs, loss of railway earnings & savings would be considered for CNG powered train.

Investment

The investment cost has been worked out based on a report on alternative fuel used in Indian Railway [3] made in collaboration "M/S Cummins India Limited", which is reputed and established entity in the field is of Diesel and CNG engines. Investment costs are given below:

1. Engine conversion cost: One of the major investment cost in dual fuel engine is conversion cost. It includes the costs of conversion kit, major components like cylinder head, gas inlet valve, electronic control unit etc, labor and other items of engine conversion. Cost of conversion kit of CNG per Locomotive is about Tk.40, 00,000/-. The total cost of conversion for Dual Fuel Engine including taxes, excise duty, freight and insurance charges comes to be Tk.50, 00,000/- approx [4].

2. Cost of CNG cascade cylinders: The cost of CNG cascade along with 96 cylinders is about Tk.25, 00,000/- and cost of setup the cascade on a BFCT (Bogie Flat Container Truck) 1, 00,000/-. Thus the total cost to make CNG tender car is Tk.26, 00,000/-.

3. Cost of building CNG filling station: Establishment cost of CNG filling station is around Tk.3, 00, 00,000 (3 crore) [10]. It will be viable if total sale of gas is around Tk.1, 00000 per day. Current price of CNG is Tk.16.75 per cubic meter.

Loss of earning

Losses of railway earning after conversion of locomotive are given below:

1. Passenger loss due to CNG tender car: An extra bogie is needed for CNG tender car. As per rule of train operation, a limited number of bogies could be added in a train. For this reason, one passenger bogie or container bogie would be reduced from a train for CNG / dual fuel engine. On average, 30 passengers run in every bogie and earning per passenger per hour is 15 taka [1]. Total loss is 450 taka per train per hour due to tender car. Passenger and earning per passenger would increase every year. Let loss would be increased 10% per year. Extra manpower, facilities and maintenance is needed for CNG tender car. Operating and maintenance cost of CNG tender car would be 5, 00,000/- per year.

2. Loss due to CNG fueling time: Fueling time of diesel Locomotive is 30 minutes. On the other hand dual fuel locomotive's fueling time is 3 hours (CNG filling rate 600 CUM/hr). Earning will be lost due to taking more time in fueling. Average earning per train-hour of BR is Tk 4000.

3. Loss due to shunting of CNG ender car: In diesel Locomotive diesel fuel tank is mounted on the Locomotive. But in dual fuel locomotive, CNG tender car is another rolling stock which is coupled behind the locomotive. During shunting and changing of locomotive it will take more time. Average earning per train-hour of BR is Tk 4000. Let it will increase 10% in every year.

Savings due to CNG conversion

The areas of savings due to duel fuel operation are given below:

1. Fuel cost: This report will compare the cost of Diesel Fuel and dual fuel on the basis of working of Locomotives per hour. CNG costs Tk. 16.75/- per CUM in comparison to the cost of Diesel of Tk.55.00/- per liter. One cubic meter of CNG produces approximately same energy as is produced by one liter of Diesel. Every CNG filling station buys natural gas from Distribution Company at the rate of Tk.9.75/- per cubic meter. Let both fuel cost will increase in every year and net savings will be increased 10% in every year. Thus, use of CNG in its pure form may result in savings of 60% of fuel consumption. In dual fuel engine of this report CNG has been proposed to replace only 50% of Diesel.

2. Fuel transportation cost: The oil companies like Padma, Meghna and Jamuna have been nominated by Bangladesh Railway for supply of HSD oil from Patenga at Chittagong and Daulatgonj at Khulna. Accordingly railway administration has been receiving regular supply of fuel oil from the above companies through railway transportation. The average transportation cost is Tk.0.22 per liter. In case of CNG, there is no extra transportation cost.

3. Lub-Oil cost: In a locomotive around 492 liter engine lubricating oil (BP Energal; SAE-40) have been used. Price of lubricating oil is 154 Tk per liter. That lub-oil is changed after every 300 hour run of diesel engine. The lub oil in a CNG vehicle need not be changed as frequently, because CNG burns clean than diesel. In natural gas, amount of heavy hydrocarbon molecule is negligible and the rate of carbon deposition after burning of natural gas is small. For this reason viscosity and transparency of lubricating oil of dual fuel engine would be sustainable longer than diesel engine. From experience it is found that lub-oil should be changed after 500-hour run of dual fuel engine. It saves operating cost due to less consumption of lubricating oil. Let lubricating cost will be increased 10% in every year.

4. Periodic maintenance cost: Cleaner burning characteristics of natural Gas and the absence of particulates often reduce engine wear and tear. CNG engine run more efficiently than a Diesel powered vehicle, thereby extending the life of the spare parts that reduce maintenance cost. Due to reduction of carbon soot build-up and cleaner lube oil, longer intervals between service maintenance can be expected, sometimes doubled.

The objective of this financial analysis is to observe the influence of investment, operation cost and savings in terms of the following parameters.

Net present value (NPV): It is the difference between the present value of cash inflows and the present value of the cash outflows generated by the investment, and discounted at the assumed hurdle rate (Minimum acceptable rate of return).

Benefit cost ratio (BCR): It is the ratio of total benefit to total cost at a particular discount rate.

Internal rate of return (IRR): IRR of a cash flow is the discount rate at which the present value of the cash flow is zero. The concept IRR determines a discount factor that becomes the 'yard stick'. IRR measures the effective rate of return earned by an investment as though the money had been loaned at that rate.

IRR = LDF + {NPV at LDF X (HDF - LDF) ÷ (NPV at LDF – NPV at HDF)}
Where, LDF = Lower discount factor, HDF = Higher discount factor

5.1.1: Analysis for a single Locomotive

Assumptions:

1. A single Locomotive is converted
2. Gas purchase from private CNG filling station
3. Average operating time of locomotive is 400 hour per month
4. Operating life of converted locomotive is 10 years.
5. Average on train running time is 300 hour per month
6. CNG refueling is needed once for two days
7. 50% diesel replaced in dual fuel mode.

Investment cost:

Cost of conversion kit of CNG per locomotive:	Tk.40, 00,000/-
Cost of CNG cascade along with 80 cylinders:	Tk.26, 00,000/-
Cost of conversion work including taxes, excise duty, freight and insurance charges:	Tk.11, 00,000/-
Total:	Tk.77, 00,000/-.

Loss of Railway earning per year:

Loss due to CNG Tender car: Passenger loss + Maintenance cost of Tender car
= (Tk 450/hr X 300 X 12) + Tk. 5, 00,000 = Tk 21, 20,000/-

Loss due to taking more time of CNG fueling: (Tk 4000/day X 365) = Tk 14, 60,000/-

Loss due to shunting of CNG Tender car: (Tk 2000/day X 365) = Tk 7, 30,000/-

(Loss 30 minutes in every day)

Total: Tk 43, 10,000/-

Table 12: Loss of railway earning (a)

year	% of loss increased	Loss due to Tender car	Loss due to fueling time	Loss due to shunting	Total loss of earning
1	1.00	21, 20,000/-	14, 60,000/-	7, 30,000/-	43, 10,000/-
2	1.10	23,32 ,000/-	16,06,000/-	8,03,000/-	47,41,000/-
3	1.20	25,44,000/-	17,52,000/-	8,76,000/-	51,72,000/-
4	1.30	27,56,000/-	18,98,000/-	9,49,000/-	56,03,000/-
5	1.40	29,68,000/-	20,44,000/-	10,22,000/-	60,34,000/-
6	1.50	31,80.000/-	21,90,000/-	10,95,000/-	65,45,000/-
7	1.60	33,92,000/-	23,36,000/-	11,68,000/-	68,96,000/-
8	1.70	36,04,000/-	24,82,000/-	12,41,000/-	73,27,000/-
9	1.80	38,16,000/-	26,28,000/-	13,14,000/-	77,58,000/-
10	1.90	40,28,000/-	27,74,000/-	13,87,000-	81,89,000/-

Savings per year:

Fuel cost savings:

In dual fuel engine, rate of diesel consumption is 40 liter / hour @ Tk 55.64 including transportation cost, tax & VAT and rate of gas consumption 42.2 cubic meter / hour @ 16.75 tax & VAT.

Fuel cost per year for dual fuel locomotive: (40X55.64X400X12 + 42.2X16.75X400X12)

= 1, 06, 82,880 + 33, 92,880

= Tk. 1, 40, 75,760/-

In diesel fuel engine, rate of diesel consumption is 80 liter / hour @ Tk 55.64 including transportation cost, tax & VAT.

Fuel cost per year for diesel locomotive: (80X55.64X400X12)

= Tk. 2, 13, 65,760/-

Fuel cost Savings per year: 21365760 – 14075760 = Tk. 72, 90,000/-

Lub-oil cost savings:

Average operating time of locomotive is 400 hour per month. Change of oil is needed 12 times for dual fuel locomotive and 20 times for diesel locomotive per year.

Lub-oil cost per year for dual fuel locomotive: (492X154X12)

= Tk. 9, 09,216/-

Lub-oil cost per year for diesel locomotive: (492X154X20)

= Tk. 15, 15,360/-

Lub-oil cost Savings per year: 15, 15,360/- – 9, 09,216/- = Tk. 6, 06,144/-

Maintenance cost savings:

Gas fuel decreased engine wear. Due to reduction of carbon soot build-up and cleaner lube oil, longer intervals between service maintenance can be expected.

Let, Maintenance cost savings per year: 1, 00,000/-

Savings of fuel cost:	72, 90,000/-
Savings of lub-oil cost:	6, 06,144/-
Savings of maintenance cost:	1, 00,000/-

Total Savings: 79, 96,144/-

Table 13: Savings due to CNG conversion (a)

year	%of savings increased	savings due to CNG fuel	savings due to lub-oil	savings in maintenance	Total savings
1	1.00	72, 90,000/-	6, 06,144/-	1, 00,000/-	79, 96,144/-
2	1.10	80,19,000/-	6,66,758/-	1,10,000/-	87,95,758/-
3	1.20	87,48,000/-	7,27,372/-	1,20,000/-	95,95,373/-
4	1.30	94,77,000/-	7,87,987/-	1,30,000/-	1,03,94,987/-
5	1.40	1,02,06,000/-	8,48,602/-	1,40,000/-	1,11,94,602/-
6	1.50	1,09,35,000/-	9,09,216/-	1,50,000/-	1,19,94,216/-
7	1.60	1,16.64,000/-	9,69,830/-	1,60,000/-	1,27,93,830/-
8	1.70	1,23,93,000/-	10,30,444/-	1,70,000/-	1,35,92,034/-
9	1.80	1,31,22,000/-	10,90,060/-	1,80,000/-	1,43,93,060/-
10	1.90	1,38,51,000/-	11.51,674/-	1,90,000/-	1,51,92,674/-

Table 14: Financial analysis (NPV, CBR) when one locomotive converted

(Figure in '000')

Year	Investment Cost	Loss of Earnings	Total Cost	Total Benefit	Discount Factor @ 20%	Total Discounted Cost	Total Discounted Benefit
1	7700	4310	12010	7996	1.00	12010	7996
2	0	4741	4741	8796	0.833	3949	7327
3	0	5172	5172	9595	0.694	3589	6659
4	0	5603	5603	10395	0.579	3244	6018
5	0	6034	6034	11195	0.482	2908	5396
6	0	6545	6545	11994	0.402	2631	4822
7	0	6896	6896	12794	0.335	2310	4286
8	0	7327	7327	13592	0.279	2044	3167
9	0	7758	7758	14393	0.233	1808	3354
10	0	8189	8189	15193	0.194	1589	2947
Total						36082	86704

For calculation data are tabulated in table 13. Cost and benefit are discounted at 20% as before total discounted cost is Tk.36082 Thousand and total discounted benefit is Tk.86704 Thousand.

Net present value (NPV) = Total benefit – Total cost

= 86704 – 36082

= 50622 Thousand

Benefit cost ratio (BCR) = Total benefit ÷ Total cost

= 86704 ÷ 36082

= 2.4

Table 15: Financial analysis (IRR) when one locomotive converted

(Figure in '000')

Year	Total Cost	Total Benefit	Net Benefit	NPV at higher discount rate of 30%		NPV at lower discount rate of 20%	
				Discount Factor	NPV	Discount Factor	NPV
1	12010	7996	-4014	1.00	-4014	1.00	-4014
2	4741	8796	4055	0.769	3118	0.833	3378
3	5172	9595	4423	0.592	2618	0.694	3070
4	5603	10395	4792	0.455	2180	0.579	2775
5	6034	11195	5161	0.350	1806	0.482	2488
6	6545	11994	5449	0.269	1466	0.402	2190
7	6896	12794	5898	0.207	1221	0.335	1976
8	7327	13592	6265	0.159	996	0.279	1748
9	7758	14393	6635	0.123	816	0.233	1546
10	8189	15193	7004	0.094	658	0.194	1359
			Total		10865		16516

Data is tabulated in table 14 for calculating IRR.

IRR = LDF + {NPV at LDF X (HDF - LDF) ÷ (NPV at LDF – NPV at HDF)}

= 20 + {16516 X (30 - 20) ÷ (16516 – 10865)}

= 20 + {(165160) ÷ (5651)}

= 20 + 29.22

= 49.22

Where, LDF = Lower discount factor

HDF = Higher discount factor

5.1.2: Analysis for a group of Locomotive

Assumptions:

1. Locomotives would be converted =10 nos
2. Gas re-fueling from own CNG filling station
3. Average operating time of locomotive is 400 hour per month
4. Operating life of converted locomotive would be 10 years.
5. Average on train running time is 300 hour per month
6. CNG refueling is needed once for two days in each locomotive
7. 50% diesel replaced in dual fuel mode.

Investment cost:

Cost of conversion kit for 10 locomotives:	Tk.4, 00, 00,000/-
Cost of CNG cascade for 10 locomotives:	Tk.2, 50, 00.000/-
Cost of conversion work including taxes, excise duty, freight and insurance charges for 10 locomotives:	Tk.1,10, 00,000/-
Cost of CNG filling station:	Tk.3, 00, 00,000/-
Total:	Tk.10, 60, 00,000/-.

Loss of Railway earning per year:

Loss due to 10 CNG tender car:	Tk.2, 12, 00,000/-
Loss due to taking more time of CNG fueling for 10 locomotives:	Tk.1, 46, 00,000/-

Loss due to shunting of 10 CNG Tender car: Tk.73, 00,000/-

(Loss 30 minutes in every day)

Loss due to maintenance and operating cost of filling station: Tk.50, 00,000/-

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Total: Tk.4, 81, 00,000/-

Table 16: Loss of railway earning (b)

(Figure in '000')

year	% of loss increased	Loss due to Tender car	Loss due to fueling	Loss due to shunting	Loss due to filling station	Total loss of earning
1	1.00	21200	14600	7300	5000	48100
2	1.10	23320	16060	8030	5500	52910
3	1.20	25440	17520	8760	6000	57720
4	1.30	27560	18980	9490	6500	62530
5	1.40	29680	20440	10220	7000	67340
6	1.50	31800	21900	10950	7500	72150
7	1.60	33920	23360	11680	8000	76960
8	1.70	36040	24820	12410	8500	81770
9	1.80	38160	26280	13140	9000	86580
10	1.90	40280	27740	13870	9500	91390

Savings per year:

Fuel cost savings:

In dual fuel engine, rate of diesel consumption is 40 liter / hour @ Tk 55.64 including transportation cost, tax & VAT and rate of gas consumption 42.2 cubic meter / hour @ 9.75 tax & VAT.

Fuel cost per year for dual fuel locomotive: (40X55.64X400X12 + 42.2X9.75X400X12)

= 1, 06, 82,880 + 19, 74,960

= Tk. 1, 26, 57,840/-

In diesel fuel engine, rate of diesel consumption is 80 liter / hour @ Tk 55.64 including transportation cost, tax & VAT.

Fuel cost per year for diesel locomotive: (80X55.64X400X12)

= Tk.2, 13, 65,760/-

Fuel cost Savings of 10 locomotives per year: (21365760 – 12657840) X10

= Tk.8, 70, 79,200/-

Lub-oil cost savings:

Average operating time of locomotive is 400 hour per month. Change of oil is needed 12 times for dual fuel locomotive and 20 times for diesel locomotive per year.

Lub-oil cost per year for dual fuel locomotive:	(492X154X12)
	= Tk. 9, 09,216/-
Lub-oil cost per year for diesel locomotive:	(492X154X20)
	= Tk. 15, 15,360/-
Lub-oil cost Savings of 10 locomotives per year:	(15, 15,360/- – 9, 09,216/-) X 10
	= Tk.60, 61,440/-

Maintenance cost savings:

Gas fuel decreased engine wear. Due to reduction of carbon soot build-up and cleaner lube oil, longer intervals between service maintenance can be expected.

Let, Maintenance cost savings of ten locomotives per year: 10, 00,000/-

Savings of fuel cost:	8, 70, 79,200/-
Savings of lub-oil cost:	60, 61,440/-
Savings of maintenance cost:	10, 00,000/-
	Total: 9, 41, 40,640/-

Table 17: Savings due to CNG conversion (b)

(Figure in '000')

year	%of savings increased	savings due to CNG fuel	savings due to lub-oil	savings in maintenance	Total savings
1	1.00	87079	6062	1000	94141
2	1.10	95787	6668	1100	103555
3	1.20	104495	7274	1200	112969
4	1.30	113203	7881	1300	122383
5	1.40	121911	8487	1400	131797
6	1.50	130619	9093	1500	141212
7	1.60	139326	9699	1600	150626
8	1.70	148034	10305	1700	160040
9	1.80	156742	10912	1800	169454
10	1.90	165450	11518	1900	178868

Table 18: Financial analysis (NPV, CBR) when ten locomotive converted

(Figure in '000')

Year	Investment Cost	Loss of Earnings	Total Cost	Total Benefit	Discount Factor @ 20%	Total Discounted Cost	Total Discounted Benefit
1	106000	48100	154100	94141	1.00	154100	94141
2	0	52910	52910	103555	0.833	44074	86261
3	0	57720	57720	112969	0.694	40058	78400
4	0	62530	62530	122383	0.579	36205	70860
5	0	67340	67340	131797	0.482	32458	63526
6	0	72150	72150	141212	0.402	29004	56767
7	0	76960	76960	150626	0.335	25782	50460
8	0	81770	81770	160040	0.279	22814	44651
9	0	86580	86580	169454	0.233	20173	39483
10	0	91390	91390	178868	0.194	17730	34700
					Total	422398	619249

For calculation data are tabulated in table 17. Cost and benefit are discounted at 20% as before total discounted cost is Tk. 422398 Thousand and total discounted benefit is Tk. 619249 Thousand.

Net present value (NPV) = Total benefit – Total cost

= 619249 – 422398

= 196851 Thousand

Benefit cost ratio (BCR) = Total benefit ÷ Total cost

= 619249 ÷ 422398

= 1.47

Table 19: Financial analysis (IRR) when ten locomotives converted

(Figure in '000')

Year	Total Cost	Total Benefit	Net Benefit	NPV at higher discount rate of 30%		NPV at lower discount rate of 20%	
				Discount Factor	NPV	Discount Factor	
1	154100	94141	-59959	1.00	-59959	1.00	-47459
2	52910	103555	50645	0.769	38946	0.833	42187
3	57720	112969	55249	0.592	32707	0.694	38343
4	62530	122383	59853	0.455	27233	0.579	34655
5	67340	131797	64457	0.350	22560	0.482	31068
6	72150	141212	69062	0.269	18578	0.402	27763
7	76960	150626	73666	0.207	15249	0.335	24678
8	81770	160040	78270	0.159	12445	0.279	21837
9	86580	169454	82874	0.123	10194	0.233	19310
10	91390	178868	87478	0.094	8223	0.194	16971
			Total		126176		196853

Data is tabulated in table 18 for calculating IRR.

$$IRR = LDF + \{NPV \text{ at } LDF \times (HDF - LDF) \div (NPV \text{ at } LDF - NPV \text{ at } HDF)\}$$

$$= 20 + \{196853 \times (30 - 20) \div (196853 - 126176)\}$$

$$= 20 + \{(1968530) \div (70677)\}$$

$$= 20 + 27.85$$

$$= 47.85$$

Where, LDF = Lower discount factor

HDF = Higher discount factor

5.2: Comparison between Diesel & Dual fuel Locomotive

Comparison between dual fuel locomotive and existing diesel electric locomotive is given below:

Table 20: Comparison with existing system

COMPARISON OF 1500 HP DUAL FUEL LOCOMOTIVE WITH DIESEL LOCOMOTIVE		
Description	Diesel Locomotive	Duel fuel Locomotive
Fuel	Diesel	Diesel & Gas
Diesel Gas ratio	100 : 0	50 : 50
Rating KVA	1250	1250
Rating KW	1000	1000
Investment cost	0	63,50,000/-
Fuel cost		
Gas consumption cum/hr	0	42.2
Diesel consumption liter/hr	80	40
Gas rate	N/A	16.75
Diesel rate	55.64	55.64
Fuel cost Tk./hr	4451.2	2932.45
Lubricating oil cost / year	1515360	909216
Total running hour / year	4800	4800
Lub oil cost / hour	315.7	189.42
Maintenance cost/hr	104.17	83.3
Total operating cost / hr	4871.07	3205.17
Savings / hour	1665.9	
Loss of railway earning due to CNG conversion	0	897.92
Net savings / hour	**767.98**	
Investment cost	7700000	
Average running hour per month	400	
Payback period in hours	8268	
Payback period in month	25	
Payback period	**2 year 1 month**	
Annual rate of return (Without interest on investment)	**48%**	

From the above calculations it is noticed that the introduction of dual fuel engine in Locomotive results in saving of Tk.768/- per Engine hour running as compared to diesel engine. Considering average Engine running of 400 Hrs per month, payback period would be one year and nine month.

But actual oil price is $135 per barrel or Tk.65 per Liter. Bangladesh Government gives subsidy on diesel oil. BR can buy it from BPC by Tk.55 per liter. If it is calculated using actual price of diesel, net saving per hour will be Tk.1042 and payback period would be 15 months. If NG is used, foreign currency will be saved.

5.3: Case Study

Two practical cases have been studied to assess the financial viability of dual fuel locomotive. One study has been done for passenger train from Dhaka to Chittagong and other for goods train from Dhaka to Akhaura.

5.3.1: Case Study for passenger train

Name of train:	Subomo Express (702)
Engine:	1500 HP / 1120 KW
Date:	05-07-08
Route:	Dhaka to Chittagong
Length of route:	320 km
Starting time:	4:20 PM
Arrival time:	11:05 PM
Running Time:	6 hour 45 min
No. of Bogie:	19
Total no of Passenger:	1060
Total diesel consumed:	852 Liter
Rate of Diesel:	Tk.55.64
Total Fuel Cost:	Tk.47, 405

As per practice of Bangladesh Railway, if one extra bogie is added with a train more 40 liter diesel should be rationed. Due to attaching a tender car with above mentioned train, it will consume 892 liter diesel. For CNG powered train, it will consume 446 liter diesel and 450 cubic meter gas. Gas rate is Tk.16.75 per cubic meter.

Then, total Fuel Cost:	Tk.32, 354
Fuel cost savings per trip:	Tk.15, 052
Operating cost reduction:	(15052 ÷ 47405) x 100 = 31.75%

5.3.2: Case Study for goods train

Name of train:	Container Train (802)
Engine:	1500 HP / 1120 KW
Date:	13/14-07-08
Route:	Dhaka to Chittagong
Length of route:	320 km
Starting time:	8:55 PM
Arrival time:	9:25 AM
Total running time:	12 hour 30 min
No. of Bogie:	29
Total diesel consumed:	1158 liter
Total Fuel Cost:	Tk.64, 431

Due to attaching a tender car with above mentioned train, it will consume 1200 liter diesel. For CNG powered train, it will consume 600 liter diesel and 630 cubic meter gas.

Then, total Fuel Cost:	Tk.43, 937
Fuel cost savings per trip:	Tk.20, 494
Operating cost reduction:	(20494 ÷ 64431) x 100 = 31.8%

CHAPTER 6

ENVIRONMENTAL ISSUES

Conventionally economic growth implies the growth of goods and services produced in an economy. Economic Growth has been considered as the precondition of human welfare and development. But the traditional system of estimating economic growth on the basis of goods and services do not consider environmental effect. But recently the emergence of the concept of sustainable development made it clear that alternative method is needed for estimating physical and economic development appropriately to measure standard of living of human being. In this method, the depletion of natural resources and environmental issues that has impact on sustainable development is taken into account.

Developing countries like Bangladesh is characterized by a rapid increase of energy consumption accompanied by a rapid growth of population and economic activities. Thus the increasing contribution of atmospheric loads of greenhouse gas to global climate change is anticipated.

Emissions

In the last few years, emissions reduction has received tremendous attention. This interest is twofold: first, its contribution to global warming and second, concern over particulate matter (PM) and nitrous oxide (NOx) emissions that affect human health because of the particles' toxicity and ground level ozone production.

The Kyoto Protocol signed to reduce carbon-di-oxide and greenhouse gas emission that is responsible for increasing global warming, meltation of avalanche and rising sea level has come into force on 17 February 2005. The Protocol has been signed by 141 countries. In December 1997, the negotiations on the Kyoto Protocol under the United Nations Convention on Climate Change Framework were completed. The Kyoto Protocol put the 39 industrialised nations under obligation to meet specific legally binding targets for emissions of six-greenhouse gas i.e. carbon dioxide, methane, nitrous oxide, hydroflurocarbons, perfluorocarbons and sulphur hexafluoride emission by 5.2 percent below 1990 levels, between 2008-2012 [16].

One approach to emissions reduction in locomotive diesel engines is the use of NG as an alternative fuel or in combination with diesel fuel (dual fuel operation). NG is a mixture of gases typically consisting of at least 90% methane (CH4), along with small amounts of ethane, propane, nitrogen, carbon dioxide, and trace amounts of other gases. In general, its composition and chemical properties should provide a clean-burning fuel with lower emissions than diesel fuel. However, the emission is not solely affected by the fuel properties, but is significantly influenced by the engine design and operating conditions.
It has been reported that BN's dual-fuelled locomotives could produce full diesel horsepower with emissions reduction of 65% NOx. The trade-off for such low NOx emissions is high CO and THC (Total Hydrocarbon) outputs. The high CO and THC emission levels are normally characteristic of dual-fuelled engines that have not been optimized for exhaust emissions. In the early versions of these modified locomotives, CO emissions as high as 300% more than diesel engines were reported.

High emissions were normally observed because of incomplete combustion of NG. Recent versions of these locomotives should produce lower CO and THC emissions because of better fuel-air ratio, improved electronic controls, and piston head designs that would enhance the combustion process. Unfortunately, limited data are available for NG fuelled locomotives exhaust emissions. The available data includes those reported for BN's EMD E3B 645-16 and MK1200G locomotives. It should be noted that BN's units were converted to improve fuel economy with minimum loss of engine power output and were not optimized for emission reduction. Table displays the data acquired for BN's EMD unit at various speeds and loads [6].

Table 21: Emissions from a Dual-Fuelled EMD Locomotive at Various Speeds

Engine		**Power Output**		**Emissions**				
Speed (rpm)	Mode	Total HP	Total KW	THC (g/hp-hr)	HC (g/hp-hr)	CO (g/hp-hr)	NOx (g/hp-hr)	PM (g/hp-hr)
900	DF	3062	2284	7.7	0.8	10	4.2	0.226
900	D	3082	2299	0.6	0.6	0.191	8.355	0.364
835	DF	2633	1962	7.0	0.18	7.9	4.22	0.17

835	D	2718	2028	0.23	0.17	0.25	8.54	0.36
750	DF	2072	1545	5.4	0.25	6.29	4.27	0.15
750	D	2057	1535	0.22	0.22	0.34	8.14	0.35

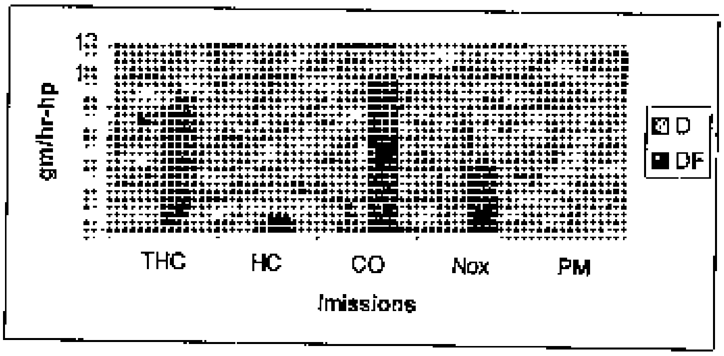

Fig 27: Emissions from diesel & dual fuel engine at 900 rpm

The use of NG fuelled locomotives provides an excellent alternative if the objective is to reduce NOx emissions. However, CO and THC emissions cannot be ignored. THC emissions from NG fuelled locomotives were found to consist of 75%-95% unburned methane. Although methane is a non-toxic gas and its emissions have not been regulated by EPA or any other environmental agency, its contribution to the greenhouse effect is comparable to that of CO2.

If a moderate increase in CO and THC emissions is allowed for locomotives, NG fuelled and/or dual-fuelled locomotives could probably meet the challenge with additional engine development and the use of oxidizing catalytic converters installed in the engine exhaust system. However, these steps would require additional resources to those already needed to introduce this type of engine for railway operation.

Environmental Improvement

In urban areas of Bangladesh, where more than 20% (more than 50% in Dhaka) of the population live, levels of motor vehicle related pollutants frequently exceed internationally agreed air quality guidelines. The significant pollutants from diesel-fueled vehicles are PM (including smoke) and NO_x exhaust. Because diesel engines operate at high air fuel ratios (30:1), they tend to have low HC and CO emissions. They have considerably higher PM emissions than gasoline-fueled vehicles. The major contribution of SO_2 in Dhaka is coming from mainly high sulfur content in the diesel fuel. At present BR has a standard for sulfur content of diesel for 0.5% (max), which is very high (Table-7). On the other hand, natural gas of Bangladesh is free from sulfur.

In an economic evaluation of air pollution in Bangladesh, the World Bank estimated that nearly 15,000 deaths would be avoided annually (10,800 in Dhaka, 2,060 in Chittagong, 1,020 in Khulna, and 975 in Bogra), if the level of air pollution in Bangladesh four largest cities reduced to the WHO annual average standard. In addition, there would be an estimated 6.5 million fewer cases of sickness requiring medical treatment; and 850 million fewer restricted activity days, respiratory symptom days, cases of lower respiratory illnesses in children, and other minor sicknesses. The economic cost of this sickness and death is estimated to be $200-800 million per year, or 0.7% - 3.0% of GDP per year [17].

Use of CNG in Railways will go a long way to improve our environmental concerns as the emission gases of CNG engine contains the harmful NO_x, and particulate matter in considerably reduced quantity which are mainly harmful for health hazards. The particulate matter is primarily responsible for air pollution of Dhaka City and smog conditions prevailing during winter over most of the area in Northern area of Bangladesh, which is the main cause for growing incidences of Asthma. The particulate matter would reduce to nil in case of CNG engine and thus the incidence of this disease is expected to come down. The reduction in green house effect will improve the global warming scenario. Similarly, reduction in NO_x in exhaust will also improve the air quality.

Emission standard of diesel Locomotive is 12.7 gm/KW-hr of NO_x and 0.8 gm/KW-hr of PM [18]. On the other hand, emission from dual fueled locomotive is 4.2 gm/KW-hr of NO_x and 0.2 gm/KW-hr of PM [6]. Using the practical data of section 5.3.1 of this report, emission from diesel locomotive per trip would be 96kg NO_x and 61kg PM. In case of using same data for dual fuel locomotive, this figure would be 43kg NO_x and 20kg PM.

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

Following calculations can be made from this study:

- Use of CNG engine is established in road transport sectors worldwide and its popularity is growing in rail sector because of its properties of clean fuel and low cost compare to diesel.

- Among the options the natural gas fueled engine technology; low pressure early cycle of dual fuel combustion system is better for BR.

- It is possible to use CNG in a dual fuel engine through conversion without any major modification in the existing system.

- Cost of CNG is less than half as compared to that of diesel for developing same amount of energy and thus the operating expenses of CNG engine would be lowered by approximately 30% in a typical dual fuel engine.

- It is considered two options of CNG fueling. In case of CNG purchase from vendor, benefit cost ratio (BCR) would be 2.4 and internal rate of return (IRR) would be 49.22. On the other hand, in case of establishing CNG fueling station, benefit cost ratio (BCR) would be 1.47 and internal rate of return (IRR) would be 47.85. After all, in both cases it is said that CNG powered train will be profitable.

- Introduction of CNG has a definite impact on environment improvement. Reduction in NOx and SOx should result in reducing green house effect and thereby improving global warming scenario. Reduction in particulate matter approximately 50 % in dual fuel engine should result in reduced smog effect and thereby minimizing the health hazards.

- The investment on CNG kit is paid back in 25 months, thereby expected annual rate of return is 48% excluding subsidy on diesel.

Advantages over the diesel engine are well known and are significant. So, the following steps are recommended:

□ Conduct a feasibility study with a view to creating a consortium and selecting technology for demonstration in Bangladesh Railway. This consortium will change the law regarding operation of explosive train, study over the safety matters, collect fund for conversion and do work transferring technology from abroad.

□ Set up an in-service demonstration, using an NG fuelled locomotive.

□ Transient response of engine in dual fuel operation both at part and full load needs to be investigated.

REFERENCES

1. Bangladesh Railway (2007): Information Book

2. WORLD Bank (2003): "Private solution for infrastructure in Bangladesh" paper A082500-L-MS-ST-BD-FR, World Bank and Public-Private infrastructure advisory facility (PPIAF).

3. Gupta, P. K. "Indian Railway Electrification", INDIA.

4. Gupta, G. K. "CNG as an alternate fuel for Railway Traction", INDIA.

5. Brinkhoff, T. (2008): World Fact Book, CIA; International Union of Railway Statistics, CANADA.

6. Taghizadeh, A. and Payne, M. L., (1999): "Review of Natural Gas Fueled Locomotive Technology", paper 13470e, prepared for Engine Systems Development Center, CANADA.

7. Eggleton, P. (2002): "Schema for Demonstrating a Natural Gas Fueled Railway Operation", paper 14016e, prepared for Engine Systems Development Center, CANADA.

8. M. L. Payne (1987): "CNG Technology seminar on Large Dual Fuel Engine Project, Bangkok" Rail and Diesel Products Division, Bombardier Inc., Montreal, CANADA.

9. Scott P. Jensen: "A Retrofit System to Convert a Locomotive to Natural Gas Operation" Energy Conversions, Inc. Tacoma, WA, USA.

10. Energy Conversions, Inc. (2006): "Economizer Dual Fuel Conversion System" report prepared by Energy Conversions, Inc. USA.

11. TGTDCL (2007): "Project Profile and Feasibility Report on Green CNG Filling Station Limited" prepared by Titas Gas Transmission and Distribution Company Limited.

12. FPC Inc. (2002): "Technical Presentation on Displacement of Diesel Fuel for Railway Locomotives with CNG" prepared by FPC Inc., CANADA for BR.

13. Tweet, T. (2002): "The ECI Dual Fuel Source Book" report "Source Book", prepared by Energy Conversions INC.

14. SN Singh: Annual Report 2004-2005 on "Motive Power". RDSO, INDIA.

15. Zishan, H. (2007): Railway Testing CNG-Powered engine, New Delhi, april 22, http://www.rediff.com/html

16. Joint UNDP / World Bank ESMAP (2006): Environment and Development (Chapter - 15)

17. Karim, M. M. & Mannan, M. S. (2002): "Feasibility of Rehabilitating Existing Railway for city commuting in Dhaka Metropolitan" Ontario, L6W 3P1, CANADA.

18. Browner, C. M. (1998): "Control of Emission of Air Pollution from new CI Marine Engine at or above 37KW", report RIN-2060-AH65, EPA, USA.

APPENDIX -A

Particulars of Locomotives in Bangladesh Railway

BR class and series no.	Type of Locomotive	HP (Bhp)	Year Built	Country / Company	Present Holding
Meter Gauge					
MEG-11 (2000)	Diesel-Electric	1125	1953	USA/GM	15
MEG-9 (2200)	Do	875	1960	USA/GM	36
MEM-14 (2300/2400)	Do	1200	1969/ 1978	CANADA/ALCO	32
MEE-5 (3100)	Do	500	1971	UK/E.ELECT	19
MEH-14 (2500)	Do	1250	1981	JAPAN/HITACHI	17
MEG-15 (2600)	Do	1500	1988	CANADA/GM	16
MEL-15 (2700)	Do	1500	1995	GERMANY/ ABB	21
MED-14 (2800)	Do	1150	1996	INDIA/ALCO	10
MEI-15 (2900)	Do	1500	1999	KORIA/Hyundai	19
MHZ-5 (3200)	Diesel Hydraulic	500	1980	HUNGERY/ Gangmavag	11
MHZ-8 (3300)	Do	800	1982	Do	11
TOTAL					207
Broad Gauge					
BEA-20 (6000)	Diesel-Electric	2000	1966	USA/ALCO	14
BEM-20 (6100)	Do	2000	1970	CANADA/ALCO	14
BEH-24 (6200)	Do	2450	1981	JAPAN/HITACHI	12
BEB-22 (6300)	Do	2250	1981	CANADA/ALCO	12
BED-26 (6400)	Do	2600	2001	INDIA/ALCO	16
BHZ-4 (7000)	Diesel Hydraulic	500	1980	HUNGERY/ Gangmavag	10
TOTAL					78
GRAND TOTAL:	285 (D-E: 253 & D-H: 32)				

APPENDIX – B

List of Loco Sheds in BR

East Zone	West Zone	
Meter Gauge	Broad Gauge	Meter Gauge
1. Dhaka	1. Iswardi	1. Parbatipur
2. Akhaura	2. Khulna	2. Bonarpara
3. Mymensingh	3. Rajbari	3. Shantahar
4. Dwangong Bazar		4. Lalmonirhat
5. Kulaura		
6. Chittagong		
7. Lakshimpur		
Total no of Loco Shed in BR: 14		

APPENDIX – C

ECI CONVERSION SPECIFICATIONS - EMD 645 TURBOCHARGED DUAL FUEL ENGINE								
ENGINE TYPE	645- DUAL FUEL TURBOCHARGED							
NUMBER OF CYLINDERS	8		12		16		20	
RPM	750	900	750	900	750	900	750	900
BHP	1200	1525	1830	2305	2460	3070	3055	3600
BKW	894.84	1137.2	1364.6	1718.8	1834.4	2239.3	2278	2684.5
EFFICIENCY								
BSFC in BTU/hp-hr								
100% load	7100	7270	7100	7190	7000	7020	6950	7000
75% load	7450	7920	7350	7561	7300	7950	7400	8000
50% load	9850	9920	9950	10000	9950	10750	9900	10000
AIR & EXHAUST SYSTEMS								
Intake air temp (77°F) CFM	3800	5000	5400	7500	7380	10000	9230	12500
Exhaust temp in (°F)	-	715	-	740	-	720	-	700
Exh. volume @ exh. temp CFM	7980	10500	11340	15700	15500	20350	19380	25100
EMISSIONS								
NHMC in g/hp-hr					0.5	0.8		
CO in g/hp-hr					6.4	9.1		
NOx in g/hp-hr					4.5	3.6		
COOLING SYSTEMS								
Water flow - after cooler circuit gal/min	90	90	150	150	200	200	200	200

HEAT REJECTION RATE								
Jacket water	28 BTU/ min/ BHP							
*After cooler	10.7 BTU/ min/ BHP							
* Baseline figures. System details affect actual values.								
FUELING RATES								
Gas Flow @ 100% load (scfm)	157	205	240	.306	318.	399	392	466
Gas Flow @ 75% load (scfm)	128	158	192	236	250	312	320	390
Gas Flow @ 50% load (scfm)	95	142	140	.212	.188	280	233	350
Diesel flow @ full load (gal/ hr)	64	77	96	115	128	154	160	192
Pilot fuel volume, roots injector gal/hr	3.8	4.5	6	7.22.	8	9.6	10	12
Pilot fuel volume, std. injector gal/hr	6.4	8.25	9.6	12.5	12.8	16.2	16	22.5

APPENDIX-D

Characteristics of Natural Gas Available in Bangladesh
(Sample 1)

Sampling Date: 27.02.08		Analysis Date: 10.03.08
Sample Location: Titas RMS of Meghnaghat Power Plant		
Temparature: 78 F Pressure: 177 psi		
	% Mole	%Wt
Nitrogen	0.643	1.070
CO2	0.185	0.485
Methane	96.073	91.556
Propane	2.213	3.953
iso Butane	0.455	1.192
N Butane	0.171	0.590
iso Pentane	0.087	0.299
N Pentane	0.049	0.212
Hexane	0.031	0.134
Heptane+	0.052	0.265
	0.041	0.245
	100	100
SG	0.5811 at ISO condition (15c & 101.325 Kpa)	
Ideal Density	0.7119 Kg/m3	
Real Gas Density	0.7102 Kg/m3	
Mole Weight	16.8344 gm/mol	
compressibility	0.9976	
Higher Heating Value	38.6939 MJ/sm3	
Higher Heating Value	1038.5669 BTU/SCF	
Lower Heating Value	34.8814 MJ/sm3	
Lower Heating Value	936.2376 BTU/SCF	

APPENDIX-E

Characteristics of Natural Gas Available in Bangladesh
(Sample 2)

Sampling Date: 09.03.08 Analysis Date: 10.03.08

Sample Location: Pipe line, Dhaka.

Temparature: 79 F Pressure: 64 psi

	% Mole	%Wt
Nitrogen	0.394	0.656
CO2	0.241	0.630
Methane	96.054	91.519
Propane	2.421	4.324
iso Butane	0.495	1.296
N Butane	0.164	0.567
iso Pentane	0.083	0.288
N Pentane	0.043	0.184
Hexane	0.028	0.119
Heptane+	0.042	0.216
	0.034	0.201
	100	100

SG	0.5812 at ISO condition (15c & 101.325 Kpa)
Ideal Density	0.7123 Kg/m3
Real Gas Density	0.7106 Kg/m3
Mole Weight	16.8380 gm/mol
compressibility	0.9976
Higher Heating Value	38.8066 MJ/sm3
Higher Heating Value	1041.5916 BTU/SCF
Lower Heating Value	34.9839 MJ/sm3
Lower Heating Value	938.9882 BTU/SCF