

**ECONOMIC AND SOCIAL COMMISSION FOR ASIA AND THE PACIFIC**

**GUIDELINES FOR CONVERSION  
OF DIESEL BUSES  
TO COMPRESSED NATURAL GAS**



**UNITED NATIONS**

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## PREFACE

The dynamic economic development of the Economic and Social Commission for Asia and the Pacific (ESCAP) region puts an increasing demand on transport services, including road transport, resulting in an annual average growth of the road vehicle fleet at 3 to 4 per cent, with an estimated total of more than 130 million registered road vehicles (1993).

Since road transport relies mainly on mineral oil products such as gasoline and diesel, many countries of the region have, therefore, to import more and more oil and oil products with resulting negative effect on the balance of payments. Besides this, air quality in urban areas, particularly in big cities, is rapidly deteriorating. The blue and black shades of exhaust gases in the streets emitted by thousands of exhaust pipes are an unmistakable sign for this. If firm measures are not taken against these emissions, the health of the people in the urban areas will be increasingly affected. In addition, some of these emission components contribute to the global climate change, the impact of which cannot yet be entirely foreseen.

There are, however, several countries in the ESCAP region which have substantial resources of natural gas. Bangladesh and Pakistan considerably rely on natural gas as their primary energy source, whereas Azerbaijan, Brunei Darussalam, China, India, Indonesia, Islamic Republic of Iran, Kazakhstan, Malaysia, Myanmar, Thailand and Turkmenistan also have large gas and petroleum resources.

Development and utilization of natural gas has become a major objective in the national economies of these countries. The motive is either to decrease the import of petrol fuels or to increase the availability of national oil resources for export. In some countries, the transport sector is the second largest consumer of refined petrol fuels after industry, and in others, the third largest after electric power generating plants. While gas, as fuel, has been widely adopted by the two latter sectors as and when applicable, the transport sector remains highly dependent on petrol fuels. However, compressed natural gas (CNG) constitutes a promising alternative.

Conversion of gasoline-driven vehicles has been successfully carried out for decades in many countries worldwide, mostly due to a price advantage of CNG over gasoline. However, it is confined in many cases to specific market segments like taxi fleets. Conversion of heavy duty diesel engines, on the other hand, has so far been limited to a relatively small number due to several obstacles, most prominently the price disadvantage of CNG compared to diesel fuel.

To provide assistance in alleviating these obstacles, this publication has been prepared by ESCAP within the framework of Phase II (1992-1996) of the Transport and Communications Decade for Asia and the Pacific (Issue: Environment, safety and health in transport) and in line with Agenda 21 (The UN Programme of Action from Rio) of the Earth Summit 1992.

The publication is based on the results of the UNDP funded ESCAP project on the utilization of compressed natural gas (CNG) in urban transport through conversion of diesel buses to CNG. This project was implemented by ESCAP in cooperation with the Hydrocarbon Development Institute of Pakistan (HDIP) Karachi Operations and the Transport Department of Pakistan Steel, and assisted by the Liquid Fuels Management Group (LFMG), New Zealand and SNV Studiengesellschaft Verkehr, Germany.

Past and on-going activities of the CNG demonstration project in Karachi, as well as the preparation of this publication, have been generously supported by the Government of Germany through Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ), the German Agency for Technical Cooperation.

The publication is intended to provide policy makers, transport planning officials, road transport managers and others concerned with a general approach to and justification for the substitution of diesel fuel by compressed natural gas in road transport, as well as with guidelines for the conversion of diesel buses to CNG.

# **I. GENERAL APPROACH TO THE SUBSTITUTION OF DIESEL FUEL BY COMPRESSED NATURAL GAS IN ROAD TRANSPORT**

## **1. Natural Gas**

### **1.1 Emissions and Their Impacts**

Road transport featuring door-to-door services is among the most popular means of transport worldwide with a total of about 430 million vehicles at present. By the year 2000, this number is predicted to rise to about 500 million.

The total number of registered road vehicles in the ESCAP region (currently estimated at more than 130 million) has been growing at an average rate of 3 to 4 per cent annually, with some countries such as China, India, the Republic of Korea, Sri Lanka and Thailand experiencing double-digit growth rates in their vehicle fleets.

The increasing number of vehicles on the road, particularly in the big cities, has considerable negative effects on the environment. Engine combustion is accountable for large amounts of toxic emissions such as carbon monoxide (CO), nitrogen oxides (NO<sub>x</sub>) and of particulates. In addition, it contributes considerably to the production of carbon dioxide (CO<sub>2</sub>) which is a major cause for the greenhouse effect. As a result, human health and environment are affected.

There has been some improvement with the development of catalytic converters, electronic injection equipment and other technical systems for road vehicles; however, the burden on the environment caused by road transport is still high and constantly increasing. Under these circumstances, substitution of conventional fuels by the "clean fuel" natural gas could help reduce emissions and lead to an effective improvement of air quality, particularly in urban areas.

### **1.2 Application Potential of Natural Gas in the ESCAP Region**

Petroleum still remains unchallenged as the most important energy source. However, natural gas features an increasing share in primary energy consumption. For example, the share of natural gas in the total use of primary energy increased from 422.1 per cent in 1975 to 11.7 per cent in 1991 in the South-East Asian region.

Figure 1 (next page) reflects the general situation regarding energy production and consumption in various parts of the globe. However, the situation is quite different for individual countries. For example, with respect to petroleum, Indonesia has a consumption of 15 million tons annually with reserves of 1,905 million tons in contrast to India with reserves of 123 million tons only and an annual consumption of 20.5 million tons. However, Indonesia is an exception, as the majority of ESCAP developing countries depend on imports of petroleum or oil products.

The demand for natural gas, including the ESCAP region, is therefore expected to be increasing, taking into account that nearly sulphur-free natural gas has advantages as a primary energy source as compared to sulphurous fuels such as brown coal (lignite) and hard coal. Its demand in the market is expected to further increase when, to counter the apprehended greenhouse effect, the use of energy sources with very high CO<sub>2</sub> emission, i.e., solid fossil fuels, would be restrained.

As a rule, natural gas can be used for all purposes where energy is required. However, the transport sector, and especially road transport, is the main consumer of petroleum (in the form



of gasoline and diesel fuels) in many countries of the ESCAP region. Road transport therefore considerably contributes to high imports of mineral oil, and a reduction in the mineral oil requirements of the transport sector would directly lead to a reduction of oil imports in these countries.

The combination of high dependency of the transport sector on mineral oil products on one hand and the relatively easy substitution of diesel and gasoline by natural gas on the other hand offers a considerable potential for increased use of natural gas.

## **2. Natural Gas as a Fuel for Road Transport**

Natural gas driven vehicles are not a novelty. Approximately one million natural gas driven buses, trucks, delivery cars, forklifts and particularly private cars are successfully used worldwide. Such countries include Argentina, Canada, the Commonwealth of Independent States, Italy, the Netherlands, New Zealand, the United States of America as well as some countries in the ESCAP region. Seen in the light of better environmental protection, the problem of alternative "environment-friendly fuels" presents itself as more and more urgent.

Natural gas is considered as a promising alternative because:

- Due to its high share of methane, a hydrocarbon with a high share of hydrogen and a relatively low carbon content, natural gas is the most environment-friendly fossil fuel;
- Natural gas can be used in normal four-stroke spark ignition engines without any technical problems. Diesel engines, however, require to be converted to CNG combustion;
- Natural gas production costs are in most cases lower than those of petrol or diesel.

### **2.1 Transport Fuels Based on Natural Gas**

Natural gas consists mainly of methane ( $\text{CH}_4$ ). In addition to this, it usually includes ethane, propane and butane, long-chain hydrocarbons, water, hydrogen sulphide ( $\text{H}_2\text{S}$ ) as well as inert gases such as carbon dioxide ( $\text{CO}_2$ ) and nitrogen ( $\text{N}_2$ ). The composition, however, depends to a great extent on the deposit.

In comparison with diesel and gasoline, natural gas has an unfavourable volumetric energy content. Therefore, natural gas can only practically be applied in transport after being processed to a fuel with higher volumetric energy content.

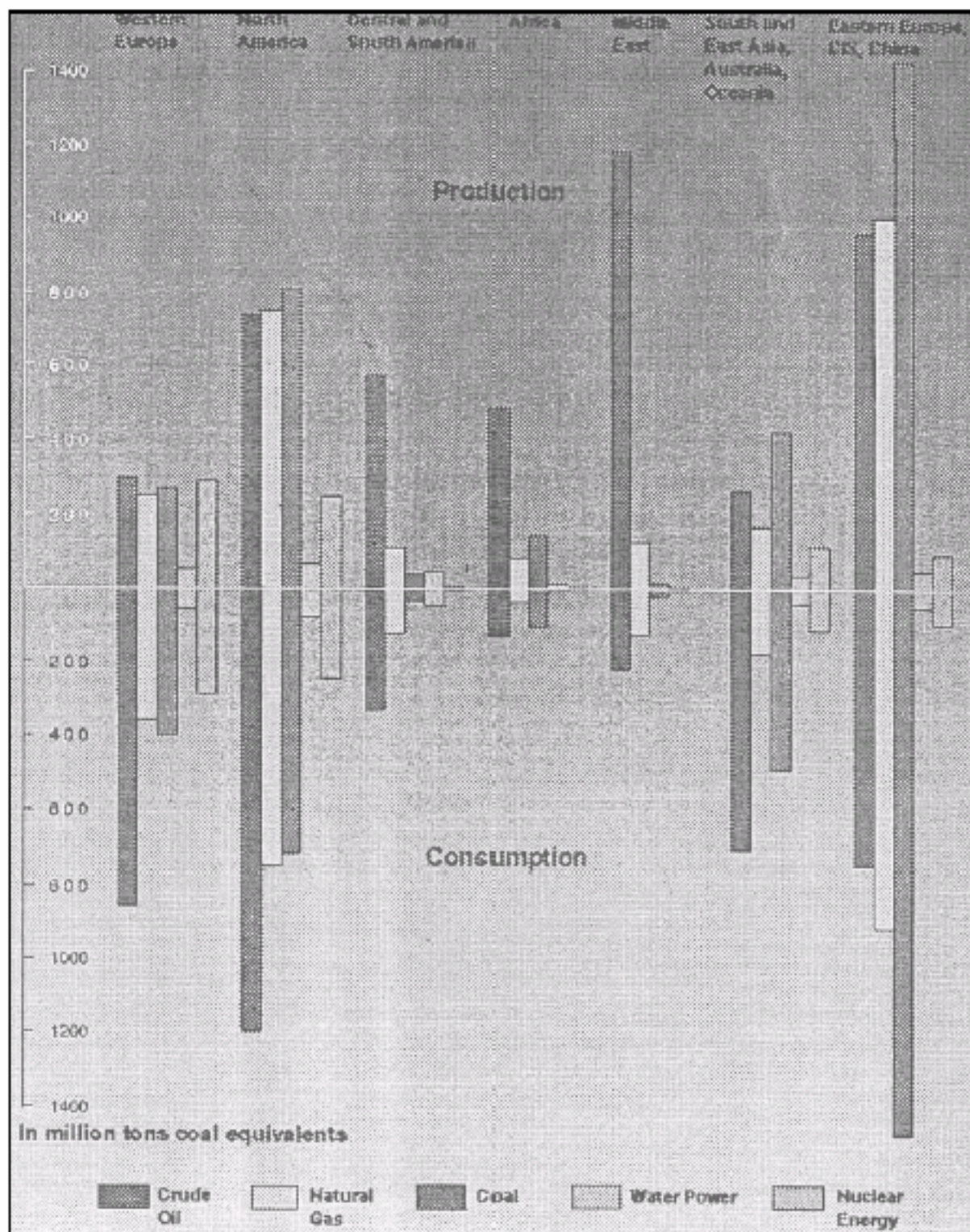


Figure 1: Energy production and consumption in 1991

Possible fuels based on natural gas are:

- Compressed Natural Gas (CNG)
- Liquefied Natural Gas (LNG)
- Methanol from natural gas
- Synthetic diesel oil from natural gas

#### Compressed Natural Gas (CNG)

Natural gas is compressed to 200 bars and carried as CNG in pressure tanks on the vehicle. The gas is usually depressurized to 7 bars by a high-pressure regulator and supplied to the engine induction system through a special mixing device.

#### Liquefied Natural Gas (LNG)

Liquefaction of natural gas is not a practical option for road transport because under normal air pressure a temperature of -161 °C needs to be maintained.

#### Methanol from natural gas

Methanol is another liquid fuel which can be produced from natural gas. However, this process requires a considerable amount of energy which in most cases is accompanied by the unwanted formation of CO<sub>2</sub>. As natural gas itself can be used as an alternative fuel, it seems illogical to process it into methanol for use in road vehicles.

#### Synthetic diesel oil from natural gas

Synthetic diesel oil can be used as another gas based fuel in road transport. However, a large quantity of energy is consumed during the manufacturing process, which increases considerably the total CO<sub>2</sub> emissions as well as the price.

In summary, Compressed Natural Gas (CNG) can be considered the most economical and practical means of using natural gas in road transport.

## **2.2 Overview of Engine Conversion Concepts**

Substituting mineral oil products by natural gas in road transport can be achieved by introducing to the market new vehicles ex-factory equipped with CNG engines, or as a first step, by converting engines of existing vehicles to CNG. To introduce natural gas as a fuel for road transport through the conversion of vehicles to CNG, the following options are possible:

- (a) Modification of a gasoline (Otto cycle) engine to CNG combustion (so called conversion to a dedicated fuel);
- (b) Modification of a gasoline engine to either CNG or gasoline (two way/bi-fuel) combustion;
- (c) Conversion of a diesel engine to dedicated CNG (spark ignition) combustion; and
- (d) Conversion of a diesel engine to dual fuel (gas and diesel combined) combustion.

For original diesel engine driven buses only options (c) and (d) can be selected, depending on the engine characteristics and the operating routines (network patterns, routes, range of operation, available refuelling network etc.).

City buses operating from a depot on fixed itineraries are, in principle, ideal for conversion to dedicated CNG combustion (option c). In that case, the diesel engine needs to be modified (converted) to a spark ignition engine in order to burn 100 per cent natural gas instead of diesel. The major modification required is a reduction of the compression ratio down to approximately 14:1, which is achieved by removal of material from the piston bowl or the exchange of pistons and/or cylinder head. Diesel injectors need to be replaced with spark plugs and a gas carburettor (mixer) has to be fixed. The diesel fuel pump also needs to be removed and a distributor (or an electronic spark ignition system) added. Additionally, in some cases a voltage converter from the standard 24 V system used on vehicles equipped with diesel engines to a 12 V system is required.

Due to the increased waste heat of the CNG combustion, resulting from the lower mechanical efficiency compared to diesel combustion, the cooling system of the engine has to be improved in many cases. That can be done by replacing the cylinder head by one with a wider diameter of the water ducts and/or by installing a larger radiator.

In the dual fuel system (option d) the quantity of diesel is reduced to a pilot injection to initiate the combustion. Dual fuel engines remain diesel, i.e. self-ignition, engines for which the energy deficit, caused by reduced diesel injection, is at any given throttle setting compensated for by natural gas mixed with the induction air. Constructional changes are minor: the injection system has to be modified to reduce diesel flow, supplemented by a gas mixer in the induction tract to supply the balancing quantity of gas to the engine. The diesel substitution rate is usually reduced to a range around 70 per cent under average bus operating/engine load conditions but can also vary considerably.

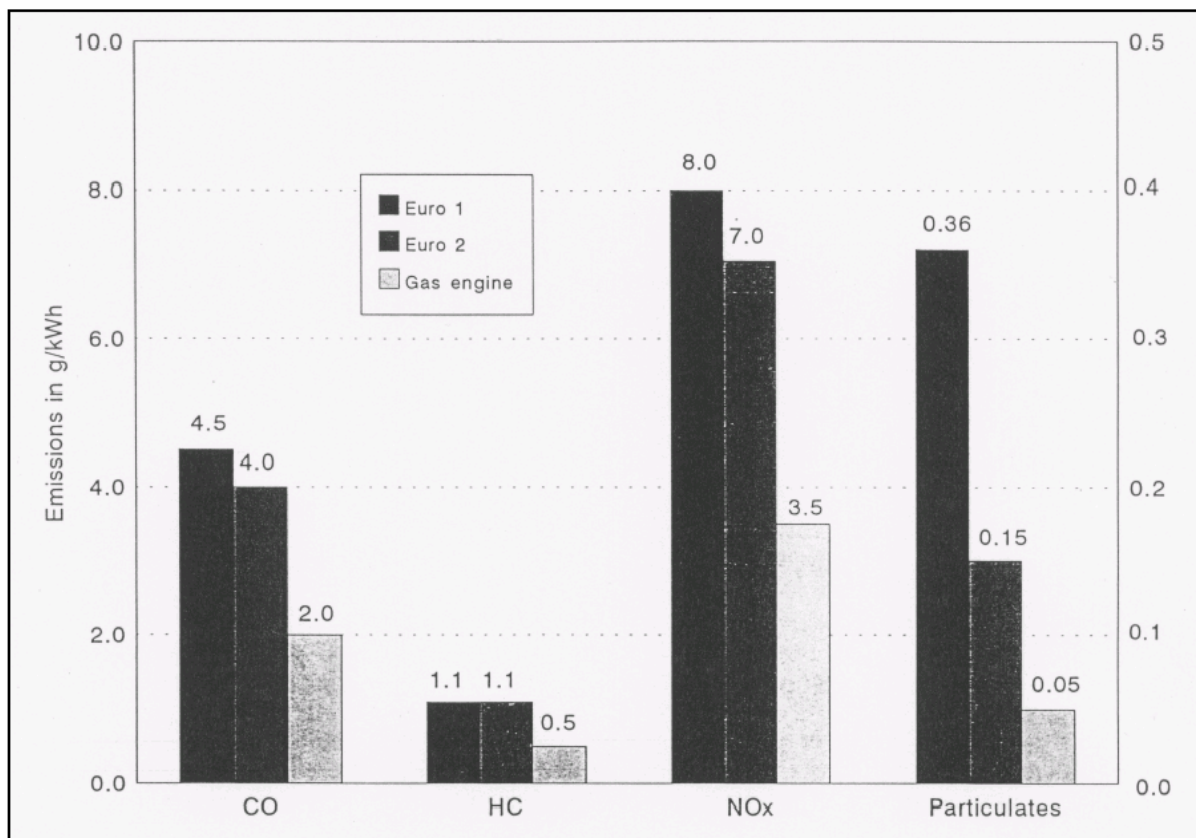
A brief description of the advantages and disadvantages of the two diesel engine conversion concepts is given in the following overview.

Diesel Conversion Concept	Advantages	Disadvantages
Dedicated CNG operation	100% substitution of diesel by CNG; low exhaust pipe emissions; higher technology level	Poor reliability under inferior maintenance conditions; qualified staff is necessary for conversion & maintenance
Dual fuel operation	Only minor engine modifications; high reliability also under poor maintenance conditions	Reduced substitution of diesel; minor reduction of exhaust emissions except for black smoke (soot)

## 2.3 Natural Gas - the Environment-friendly Fuel

Natural Gas is an environment-friendly fuel. Emission values which can be achieved by CNG engines are clearly below the present Euro 1 Standard (European emission limits for vehicles driven by diesel engines). They are even lower than the much more rigid requirements of the Euro 2 Standard which will become effective in 1996 (Figure 2), and still lower or equal to the proposed Euro 3 Standard to be effective in 1999. From the environmental point of view this speaks for itself.





**Figure 2: Emissions by an ex-factory natural gas engine (with 3-way catalytic converter under operating conditions) as compared with EURO 1 and EURO 2 requirements**

The substances emitted to the atmosphere as a result of the fuel-burning process which takes place in an internal combustion engine can be grouped as follows:

- Toxic substances with a local effect, for example in conurbations (smog), such as nitrogen oxides ( $\text{NO}_x$ ), carbon monoxide (CO), (long-chain) hydrocarbons (HC) and secondary products such as ozone ( $\text{O}_3$ ); and
- Substances with a global effect (greenhouse effect) such as carbon dioxide ( $\text{CO}_2$ ) and methane ( $\text{CH}_4$ ).

These two groups of substances work in different ways. Local toxic substances have a direct irritant or even poisonous effect on human health, whereas  $\text{CO}_2$  is a non-toxic component of our natural environment, but its larger concentration in the air on a global scale results in the warming of the atmosphere (greenhouse effect).

The current European test procedures for gasoline and diesel engines (EC-91/441) stipulate the following emission limits:

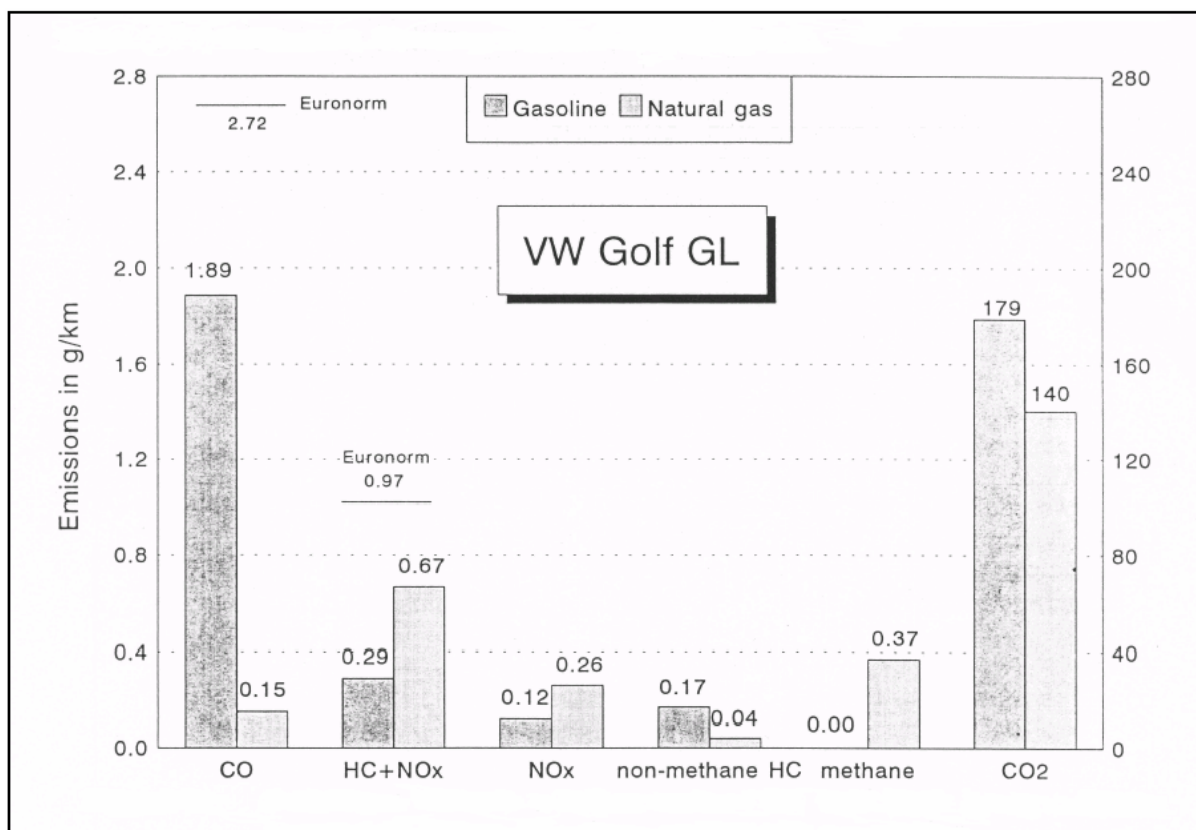
CO	< 2.72 g/km
HC plus $\text{NO}_x$	< 0.97 g/km

In future, however, the trend both in Europe and the United States of America is likely to be towards the ultra low emission vehicles (ULEV) standard. The ULEV limit values are:

CO	< 1.06 g/km
HC (without methane)	< 0.025 g/km
NO <sub>x</sub>	< 0.124 g/km

### 2.3.1 Natural Gas versus Gasoline

A Volkswagen Golf converted to CNG but with a choice of two fuels - gasoline or natural gas - offers the possibility to directly compare natural gas and gasoline operation on the same vehicle (with the engine, however, still being optimized for gasoline and not CNG operation). Results of a comparative analysis undertaken by the Technical Control Board (TÜV) in Hanover, Germany are illustrated in Figure 3.



**Figure 3: Emissions of toxic substances in a VW Golf (with 3-way catalytic converter) during natural gas and gasoline operation**

In general, the advantages and disadvantages of natural gas operation as compared with gasoline operation can be summarized as follows:

### Advantages of CNG:

- 20 to 25 per cent less carbon dioxide;
- Up to 90 per cent less carbon monoxide;
- 75 to 90 per cent less non-methane hydrocarbons;
- Approximately 80 per cent less ozone-generating potential;
- No acrid smell from exhaust gases;
- No heavy metal additives necessary to increase knock rating;
- No losses through vaporization from the tank and/or while refuelling;
- No carcinogenic substances;
- No transport by road because natural gas is normally supplied via pipelines.

### Disadvantages of CNG

- Methane emission;
- Approximately 50 to 100 per cent more nitrogen oxides in comparison with gasoline (with regulated 3-way catalytic converter);
- 10 to 20 per cent less power output with existing engines (which have been optimized for gasoline and not for CNG operation);
- Additional fuel station network necessary;
- Weight and space requirements for gas cylinders in a vehicle;
- Shorter operating range of vehicles.

In summary, combustion of natural gas in an engine leads to overall fewer toxic substances. Carbon monoxide and non-methane hydrocarbons are reduced by up to approximately 90 per cent compared with gasoline, even without a catalytic converter. The 3-way catalytic converter designed for gasoline remains largely ineffective for the degradation of nitrogen oxides and methane in natural gas operation due to the low carbon monoxide values. Further improvements can be achieved by using engines and catalytic converters optimized for natural gas.

### 2.3.2 Natural Gas versus Diesel Fuel

As briefly described earlier in Section 2.2, for conversion to CNG operation a diesel engine first has to be modified to a spark ignition engine. Results of comprehensive tests and investigations on an engine test bed are reflected in Table 1 for different engine concepts, both with diesel and CNG combustion.

Vehicles to be converted in countries of the ESCAP region would regularly have naturally aspirated engines. For these vehicles, a reduction of more than 75 per cent of nitrogen oxides (NO<sub>x</sub>) and more than 90 per cent of carbon monoxide (CO) can be expected. CO<sub>2</sub> emission will be reduced by 35 per cent with almost complete elimination of soot. This relief of environment stands against an increase in total hydrocarbon (HC) emission (including non-toxic methane) by about 90 per cent.

Engines	NO <sub>x</sub> (g/kWh)	HC (g/kWh)	CO (g/kWh)	Particulates (g/kWh)
<b>Diesel</b>				
Naturally aspirated engine	14.0	1.2	4.0	0.55
Turbocharged engine	14.0	0.4	1.4	0.40
Turbocharged engine with intercooler	8.0	0.4	0.9	0.20
Turbocharged engine with intercooler and soot filter	8.0	0.3	0.9	0.08
<b>CNG (with catalytic converter)</b>				
Naturally aspirated engine, lean mixture	3.0	2.3	0.2	<0.05
Turbocharged engine, lean mixture	4.5	2.0	0.8	<0.05
Naturally aspirated engine, lambda=1 mixture	0.5	0.5	2.8	<0.05
Turbocharged with intercooler, lambda=1 mixture	0.7	0.4	0.4	<0.05

**Table 1: Average emission values of different diesel and CNG engine concepts, measured in the 13-step test according to ECE-R49**

In the case of new vehicles, however, a regulated 3-way catalytic converter should be included. From the environmental point of view, a gas engine with a regulated 3-way catalytic converter would be the most promising solution to achieve emission reductions of more than 90 per cent for all relevant pollutants.

In general, it can be said that the typical characteristics of a diesel engine, i.e., the emission of particulates (soot) and the respective nuisance do not occur in CNG operation. In addition, bad smell from unburnt non-methane hydrocarbons is considerably reduced as is engine noise.

The emission control technologies for diesel engines, however, require the use of an oxidizing catalytic converter. This, together with the use of a soot filter, still in the development stage, makes the exhaust gas treatment technology of diesel engines expensive. Thus, for heavy duty diesel engines for buses or vans CNG seems to be the best alternative fuel for public transport in urban areas.

### 2.3.3 Future Development of CNG-driven Vehicles

Most cars and light commercial vehicles using CNG can be switched from gasoline to natural gas and vice versa. Their engines are at present usually optimized for gasoline operation. The next generation of vehicles is expected to have engines designed for CNG and to be equipped with electronic ignition control systems, thus optimizing operation regardless of the operation mode.



In addition to steel cylinders widely used to store CNG in vehicles, aluminium cylinders or composite materials such as steel/fibre glass or aluminium/fibre glass cylinders are being introduced to reduce weight. Research is also being undertaken to make the gas storage systems on vehicles lighter and increase the gas storage capacity. A promising way therefore seems to integrate the storage units in or at the roof of buses.

### 3. Potential for the Conversion of Diesel Vehicles to CNG

To develop an efficient strategy for the promotion of CNG as a substitute for diesel fuel in road transport, it is necessary to assess the market potential. Planning and implementation of concrete measures for the conversion, as well as an assessment of environmental and economic impacts would require reliable data and updated information on vehicles best suited for conversion from diesel to CNG.

#### 3.1 Target Market

Since this publication is based on a UNDP/ESCAP CNG demonstration project in Karachi, Pakistan, the analysis carried out in the following chapters is primarily based on data and conditions of Pakistan. However, the sample calculations are structured so as to enable the reader to adapt them to their country specific situations.

As a first step, the share of diesel vehicles has been estimated for each vehicle class in order to assess the market potential (Table 2).

Since motorcycles and motor rickshaws are not suitable for CNG conversion, these classes will be disregarded in the following account.

Vehicle Class	Class Definition	Per cent of Vehicles Using Diesel
Motorcycle	Motorcycles and scooters	0
Motor Rickshaw	3-wheel passenger vehicles	0
Motor Car	Cars, taxis, jeeps and all other light vehicles	5
Wagons/Minibus	Wagons and vehicles with seating capacity of less than 20 passengers	15
Van/Pick-up	Goods vehicles up to one tonne capacity	10
Tractor	Agricultural tractors	80
Bus	Seating capacity of more than 20 passengers	100
Truck	Goods carriers with or without trailers over one tonne capacity	100

**Table 2: Share of diesel vehicles by vehicle class**

Mileage patterns and specific fuel consumption are important indicators in determining vehicles which are best suited for the substitution of diesel fuel by CNG. These data are presented in Table 3.

Vehicle Class	Specific Fuel Consumption (litres/km or litres/hour*)	Average Duty (km/year or hours*/year)	Average Unit Fuel Consumption (litres/year)
Motor car	0.10	15,000	1,500
Wagon	0.11	35,000	3,850
Van/Pick-up	0.11	35,000	3,850
Tractor*	5.90	1,300	7,670
Bus	0.33	70,000	23,100
Truck	0.33	70,000	23,100

\* Figures for agricultural tractors are provided on the basis of hours instead of kilometres

**Table 3: Diesel vehicle fuel consumption characteristics**

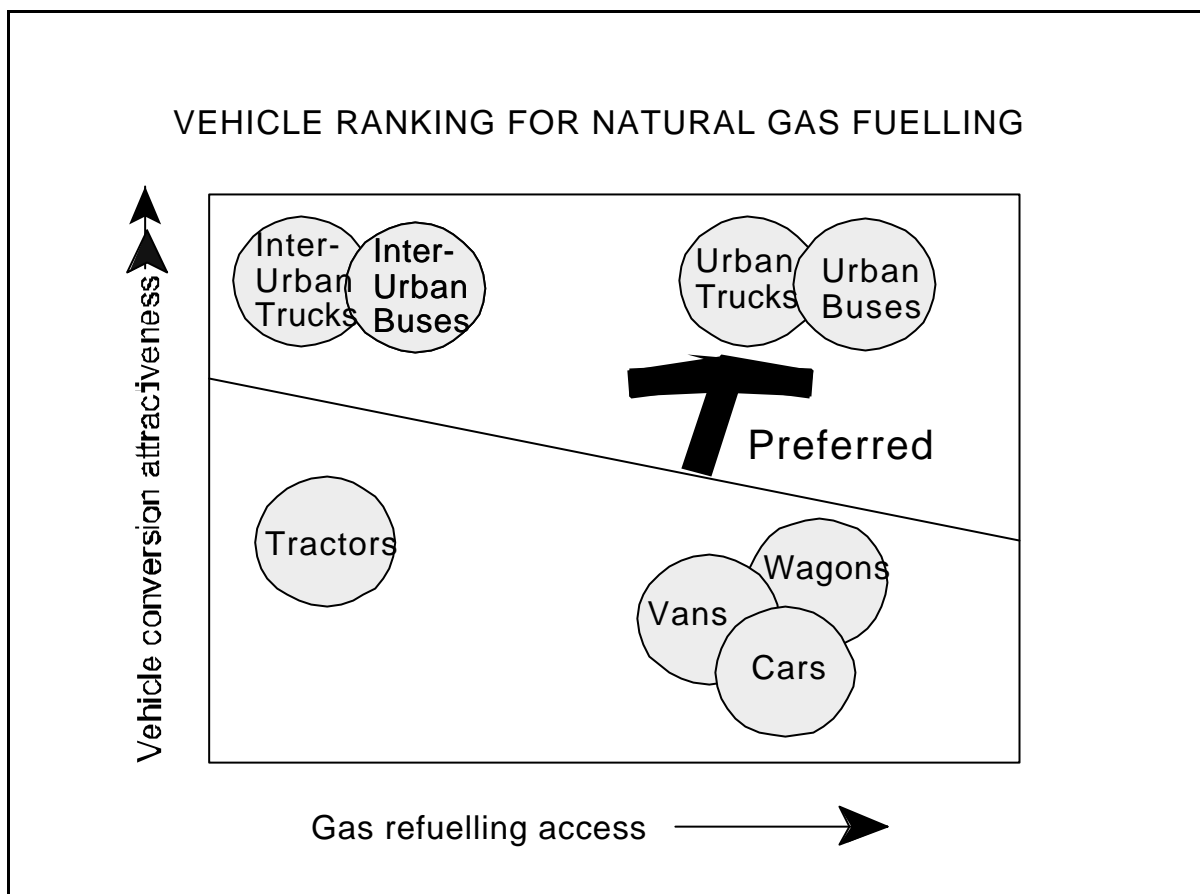
It may be noted that vehicles grouped under Motor Cars, Wagons and Vans/Pick-ups have low specific fuel consumption figures as well as low average annual use figures (mileage), resulting in low annual diesel consumption figures. Although many vehicles in these classes operate in urban areas and may have access to existing and/or planned CNG stations primarily set up to serve gasoline vehicles converted to CNG operation, or could operate from depots served by private refuelling facilities, on the basis of their low diesel consumption, they may not be considered the best suited primary target market groups.

Agricultural tractors are large consumers of diesel. However, they can also be considered as an unsuitable target market because of their diverse ownership and dispersed operational environments, making provision of refuelling arrangements difficult.

The total fuel consumption for buses and trucks is very high. These classes are the largest consumer groups of diesel. Vehicles in these classes have by far the highest specific fuel consumptions and average annual duties of all vehicles.

Buses and trucks which operate primarily in or around urban centres will have better access to refuelling facilities than those operating on long distance, inter-urban routes. These facilities may be public CNG stations or privately owned facilities servicing a fleet. In general, buses operate along defined routes and, at least once a day, return to their depots. Their access to gas is therefore better than that of trucks which tend to have more diverse operational patterns.

A qualitative ranking of preference for natural gas to diesel fuelling, based on the above analysis, is illustrated in Figure 4 which compares attractiveness for vehicle conversion (based on average fuel consumption for vehicles classes and share of diesel vehicles) with CNG refuelling access. The group title "Urban" has been used for vehicles which operate over short distances, usually in or around cities, travelling within 200 km range before returning to their bases. The group title "Inter-urban" designates vehicles which travel over distances of more than 200 km from their bases. These trips are commonly between distant city centres, but may include any long-distance travel.



**Figure 4: Vehicle ranking for natural gas fuelling**

Summing up, the primary target market for the conversion of diesel vehicles to CNG fuelling are buses and trucks in urban transport. Among them, preference should be given to city buses due to their limited and regular operating patterns and their, in many cases, large fleets which might justify the establishment of own CNG refuelling stations.

### 3.2 Options for Changing Diesel Vehicles to CNG Operation

There are three basic alternatives for changing vehicles in the target market to CNG fuelling:

- (a) Ex-factory CNG vehicles: New vehicles with gas engines, purpose-built and optimized for CNG fuelling are introduced into the market.
- (b) Engine exchange: Diesel engines of existing vehicles are swapped for either gas engines or for diesel engines which have already been converted to gas operation, and diesel fuel systems replaced with CNG fuel systems.
- (c) Retrofit-conversion: Engines of existing vehicles are converted to gas operation and diesel fuel systems are replaced (or supplemented) with CNG fuel systems.

The ideal for a CNG programme would be the ex-factory CNG vehicles (option a). However, CNG vehicles are not yet available from production line in most countries because of the insufficient public demand for new CNG vehicles. Nevertheless, in some countries of the ESCAP

region, such as Thailand and Australia, imported factory-built CNG buses are already in operation.

Engine exchange and retrofit conversion of existing diesel buses (and trucks) are options that can be used to stimulate the market for CNG vehicles and CNG refuelling stations. This has been done in Argentina, for example, which currently enjoys a flourishing CNG programme through carefully planned policy and pricing strategies, and where production line CNG buses and trucks are now available.

### 3.2.1 Ex-Factory CNG Vehicles

New production-line CNG buses would have all guarantees of new diesel vehicles as well as a high public perception of reliability of the manufacturer's products. There would be less customer resistance to this "new fuel" if it is effectively endorsed by vehicle manufacturers by the production of CNG vehicles. An additional cost of US\$ 1,000 - 2,000 for the CNG engine and US\$ 1,200 - 2,500 for the CNG storage cylinders may, however, be expected on the price of a new CNG bus in the medium term. At present, ex-factory CNG engines including equipment are approximately 20 per cent more expensive due to low production figures.

Clear government policies and fuel pricing strategies must be in place to encourage vehicle manufacturers to produce new CNG vehicles. This would require the involvement of vehicle manufacturers in discussions concerning different aspects of a CNG programme at all levels.

### 3.2.2 Engine Exchange

In some countries of the ESCAP region, such as in Pakistan, engine exchange is already being undertaken for converting gasoline vehicles to bi-fuel CNG/gasoline (or to diesel) operation, in order to take advantage of the lower price of CNG (or diesel) as compared to gasoline. A coordinated specialist engine exchange centre could be set up as part of a diesel engine conversion programme.

The ideal time to convert an existing diesel bus to CNG fuelling is when it requires an engine overhaul and the engine has to be removed from the vehicle. The existing diesel engine is replaced with either a gas engine or another diesel engine which had been retrofitted for gas operation and pre-tested. The diesel fuel system is exchanged for a CNG fuel system (including storage cylinders) at the time of the engine swap.

A new guaranteed CNG engine would be a good incentive for bus operators. In most countries, only a limited range of heavy diesel engines is available in the market, and therefore an engine exchange centre would not have to maintain an extensive stock of engines.

### 3.2.3 Retrofit Conversions

Retrofit conversion is a simple way of introducing CNG buses under a CNG conversion programme. However, it is crucial to ensure that conversions are undertaken by suitably qualified mechanics on appropriate vehicles. Substandard conversions and conversions of inappropriate vehicles can result in inadequate vehicle performance of CNG buses which can lead to a poor public perception of CNG and jeopardise the entire CNG programme.

### 3.3 Guiding Criteria for CNG Market Development

The principal driving force in the development of a CNG conversion programme and development of a CNG market is user economics. There must be sufficient direct savings in operating costs for vehicle operators to consider changing from the familiar status quo of diesel vehicle operation to a "new fuel". The essential requirement for the development of a market through fuel cost savings is a sizeable difference between the price of CNG and that of diesel to attract vehicle operators. In addition, CNG station operators and gas distributors must be able to make sufficient profit out of this new venture.

Vehicles which will provide the highest cost savings by changing from diesel fuelling to CNG will exhibit the following characteristics:

- (a) High annual mileage resulting in high total fuel consumption;
- (b) High specific fuel consumption resulting in high total fuel consumption;
- (c) Low vehicle age so as to obtain maximum return from the conversion during the remaining life of the vehicle;
- (d) Low total cost of conversion to CNG;
- (e) Adequate standard of maintenance;
- (f) Operating patterns within accessible distance of a CNG filling station or along a well-defined route which will be serviced by CNG stations; vehicle fleets, e.g. urban buses, operating from a depot are therefore ideal candidates;
- (g) Operating patterns which allow frequent refuelling to minimize the number of CNG cylinders which are a high cost item.

In the selection of vehicles for conversion, their age, type and mechanical condition will have a strong bearing on their suitability for retrofit conversion or engine exchange. Effectively, a bad diesel vehicle will make a bad CNG vehicle. Engine modifications necessary for diesel conversion may exclude some engine types from retrofit conversion.

Another very important factor in the success of a CNG programme is the attitude of the vehicle operator to the conversion. The attitudes of diesel vehicle operators to the maintenance and management of their vehicles in the past would be a good indicator of their likely success in a CNG programme. In the same way as a bad diesel bus will make a bad CNG bus, an unsatisfactory diesel bus operator will make an unsatisfactory CNG bus operator. Vehicle operators with vehicles for which maintenance has been deferred to save costs in the short term may be attracted to CNG fuelling for further cost saving reasons, and to take advantage of any other incentives that may be available in a CNG programme. Such operators should not be included in the programme.

Any fault or breakdown which occurs to a bus converted to CNG fuelling is likely to be blamed on the new fuel, despite the actual cause of the fault, and will result in a poor perception by the public of CNG as a fuel for transport. Therefore, it is important that buses converted to CNG fuelling are maintained in good condition.

Captive fleets of vehicles are ideal candidates for CNG because of their vehicle operating patterns, and also because it is relatively simple to coordinate and manage the conversion of large private and public fleets as compared to that of sectors with a wide diversity of vehicle ownership. Individually owned vehicles are likely to require the greatest administrative effort per vehicle conversion during the implementation of a CNG programme.

Bringing together the above criteria for a CNG conversion programme and the development of a CNG market in principle, the following ranked options exist:

- (a) New ex-factory CNG urban buses (and trucks) operated in captive fleets;
- (b) Existing buses not more than 3 to 5 years old, with engine conversion (exchange or retrofit) operated in captive fleets; and
- (c) New ex-factory CNG urban buses (and trucks) independently operated.

However, for fleet operators in many developing countries in the ESCAP region, the first option is at present not feasible for financial reasons because the prices of ex-factory CNG buses are still considerably high. Thus, at this initial stage, conversion of diesel engines of existing buses to CNG is basically the only available option.

The economic and environmental impacts of large-scale conversion of diesel buses are described in the following chapter.

#### **4. Economic and Environmental Impacts of Large-scale Conversion of Diesel Buses to CNG**

After having defined urban diesel buses as the primary target for the intended substitution of diesel fuel by natural gas in its compressed form (CNG), and the (retrofit) conversion of diesel engines as the initial stage to achieve this objective, this chapter describes the economic and environmental impacts of a large-scale conversion programme. However, it is beyond the scope and the purpose of these guidelines to present a comprehensive economic analysis; therefore, the effects of a CNG programme are presented here partly in a descriptive manner. Example calculations given are either generalized or refer to the situation in Pakistan in which case they can be modified to specific situations in other countries of the region.

The large-scale conversion of buses from diesel fuel to natural gas operation has mostly economic impacts on a country. The major changes are with regard to:

- (a) Balance of payments;
- (b) Supply infrastructure for CNG;
- (c) Automotive trade and industry;
- (d) Bus operating costs;
- (e) National budget; and
- (f) Quality of life in conurbations.

The impacts on most of these areas can be described in monetary terms, except for the last one which has indirect effects on the economy, and is commonly quantified only in physical terms. An impact analysis has been carried out in the following account with the available data, demonstrated by sample calculations.

## **4.1 Balance of Payments**

Reduced mineral oil consumption has a direct impact on the balance of payments. The improvements are directly dependent on the number of buses converted to CNG and are related to either importing less or - in the case of oil exporting countries - exporting more mineral oil.

Part of the savings due to reduced mineral oil imports will, however, have to be spent on the import of CNG conversion equipment and components for the natural gas refuelling infrastructure - at least during the initial phase. There is, however, essentially a difference in the effects of these imports. The import of natural gas technology mostly constitutes capital goods which are of benefit to a country's economic development and stimulates domestic production, whereas the mineral oil needed for fuels is in many cases consumption related with little or no direct impact on domestic productivity. Therefore, the economic benefits of importing equipment for CNG use can be considered higher than that of mineral oil. Moreover, the increase in the domestic production of natural gas is of benefit to a country's economy, because the real output necessary for production and distribution of natural gas takes place domestically (with the exception of technical equipment), thus creating new employment opportunities.

As an example, the possible foreign exchange savings for Pakistan are estimated as follows: If only 15 per cent of all urban buses, i.e. about 4,200 buses, are converted to CNG, a substitution of 97 million litres of diesel would result, assuming average annual unit consumption (Table 3) and 100 per cent gas fuelling of the converted buses. This would correspond to approximately 94,000 tons of petroleum. If imports were reduced accordingly, the balance of payments would be relieved by about US\$ 12.5 million annually.

On the other hand, approximately US\$ 3,000 worth CNG equipment per bus would have to be imported, amounting to about US\$ 12.6 million. Theoretically, this additional foreign exchange could be recovered by the oil import savings within a period of one year. Assuming a CNG introduction period of 10 years (and the same service life of bus and equipment), it will diffuse accordingly, resulting in a net foreign exchange savings of US\$ 11.2 million annually, or more than 2 per cent of the average value of crude oil imports during, for example, the 1986 - 1992 period. If, in addition, 10 per cent of all trucks and cars were converted, the resulting net savings could amount to US\$ 40 million annually or 8.5 per cent of the value of oil imports.

## **4.2 Supply Infrastructure for CNG**

The operation of natural gas vehicles necessitates a supply network in order to have the vehicles refuelled within their operating range. This refuelling network can be built up supplementary to the existing network of filling stations for diesel and gasoline. However, these CNG stations will have to be regularly supplied via pipelines or, alternatively, by refuelling trucks - the mother-daughter CNG station principle.

It is reasonable to expect that the number of CNG stations will reflect the number of CNG vehicles on the road, particularly when considering the primary target market for the first few years of a CNG programme, i.e., fleets which are likely to have central CNG stations to suit their requirements. However, during the initial stage, it is most likely that CNG stations would be operating below capacity, thus grossly under utilizing the capital investment because of the small number of vehicles converted to CNG.

The containerized type of CNG stations, which have now become common, can be installed very quickly with minimum site preparation requirements. Such a CNG refuelling station can typically compress 500 cubic metres of natural gas to CNG per day. Assuming that during the introductory phase the CNG stations operate at 50 per cent capacity i.e. 10 hours per day, it is estimated that each station provides 5,000 cubic metres CNG per day or approximately 1.6 million

cubic metres annually, which is sufficient for about 60 buses operating 250 km daily. At full capacity it would however be sufficient for approximately 120 - 150 buses or, alternatively, 2,000 cars. The capital costs are estimated at US\$ 200,000 (exclusive of import duties) for the imported components and US\$ 100,000 local costs for civil works, land acquisition and connection to the gas pipeline network with a lifetime of 20 years. The annual capital costs could thus be calculated as follows:

$$C = P \times \frac{(1+i)^s \times i}{(1+i)^s - 1} \quad (1)$$

where:

$C$	=	investment costs/year (depreciation and interest)
$P$	=	purchase price of CNG-station
$s$	=	service life of CNG-station (20 years)
$i$	=	notional interest (10 per cent)

Based on the above assumptions, the annual costs would amount to US\$ 35,200. To recover this capital investment over the price of gas, the annual costs will have to be distributed over the annual production. Thus, if 1.6 million cubic metres CNG are sold per year, the CNG retail price has to be increased by US¢ 2.2 per cubic metre to cover the annual capital cost over the price. After adding the operating costs (energy, maintenance, staff etc.) of the station and the profit margin for the operator, the net increase in price would be approximately US¢ 4.0 per cubic metre CNG.

In the sample case of Pakistan, an extensive gas transmission and distribution network already exists. Surplus capacity in this network can be used to distribute natural gas as a transport fuel and, accordingly, no additional gas recovery or pipeline investment is necessary other than individual, local gas connections. The CNG programme, thus, can be described as a "marginal project", as typical around the world. However, if any country is considering CNG for road transport not as a marginal project but as the driving force behind the introduction or expansion of a gas transmission or distribution network, the costs of the gas network would need to be included while considering the economic impact of a large-scale CNG conversion programme.

In either case, however, it is necessary that conducive policy conditions and fuel pricing structure exist for the target markets to respond to the CNG programme. This has already started in some countries of the ESCAP region with the abolition of import duties on CNG stations and on retrofit conversion equipment. Since a successful CNG programme will depend on the voluntary cooperation of all parties involved, it has to be attractive to the CNG station operator as well.

Full recovery of capital invested over the CNG price would reduce the competitiveness of natural gas against diesel fuel. Thus, an incentive package by the government is imperative. Such a package may include reduced taxes on CNG, soft loans or other financing models for capital investment. For example, in the above sample calculation, a reduction of the interest rate to 3 per cent would result in a CNG price reduction of about US¢ 1.0 per cubic metre.

Such governmental support for the CNG supply infrastructure would give an important signal for the increased use of natural gas. Of course, these financial outlays which are necessary for triggering off development could initially burden the state budget, but in the long run, it would produce profitable results after the propagation of natural gas vehicles in terms of reduced mineral oil imports and sustainable economic development of the country. When the operation of natural gas vehicles becomes widespread, participation by the state in the financing of supply infrastructure will no longer be necessary.



### 4.3 Automotive Trade and Industry

At present, there are very few CNG-conversion and maintenance workshops or centres for the conversion of diesel engine vehicles to CNG operation in the ESCAP region. However, as soon as the conditions for an increased share of natural gas driven buses and trucks exist, this branch of industry is expected to progress, accompanied by a gradual development of respective human resources and auto-mechanical support infrastructure from conventional to natural gas driven vehicles.

As compared to conventional vehicles, dealing with natural gas takes place at a higher level of technology, in particular regarding heavy duty vehicles like trucks and buses. Therefore, it necessitates higher qualification and respective vocational training of technical personnel responsible for conversion and maintenance of vehicles. Intensified vocational training of personnel might need to be initiated with the assistance of foreign experts during the early stages of a CNG programme, but should be in the general interest of many developing countries of the ESCAP region which are rich in gas resources.

The change of the vehicle fleet structure in favour of natural gas vehicles will in course lead to an increase in the know-how of the labour force in the auto-mechanical trade and the automotive parts industry. Such qualification is, in any case, desirable for the economic development of a country and may, in addition, result in an accelerated technological development. This will particularly hold true if imported CNG equipment is gradually substituted by domestic products.

It has been proved in Malaysia that such development is possible. The development of an indigenous motor vehicle industry in Malaysia, initiated with foreign support combined with training and know-how transfer, continued successfully and quite independently. To achieve this, particular emphasis was laid from the very beginning on a high share of domestic real net output, whereby only components which could not be economically produced locally were initially imported with low custom duties in the interest of the overall programme.

However, the first step in pursuing the conversion of diesel vehicles to CNG on a large scale, shortly after or parallel with a CNG demonstration project to convince vehicle operators, would be the establishment of CNG conversion and maintenance facilities. Since the primary target group is the city bus fleet, it would be preferable to establish, during the initial stages, larger conversion centres in proximity to existing bus depots.

The capital costs for a conversion centre with a capacity of 350 to 450 bus conversions per year (or approximately 1,700 to 2,300 car conversions) are estimated at approximately US\$ 400,000, comprising US\$ 200,000 for civil works, US\$ 50,000 for equipment and US\$ 150,000 for land acquisition. The latter figure, however, would be grossly dependent on the specific situation at a given location. Applying the equation and assumptions of the previous section, the annual capital costs would amount to about US\$ 47,000.

Assuming a technical staff of ten (seven mechanics, one supervisor and two engineers) and other running costs (power, maintenance etc.) taken at 5 per cent of the capital cost excluding land, the yearly operating cost of a conversion centre is estimated for Pakistan at US\$ 44,000. The total cost of a conversion centre would thus be US\$ 91,000 per annum or US\$ 200 - 250 per bus conversion (excluding equipment) at full capacity. However, full utilization cannot be expected during the initial phase which would increase the cost per bus by US\$ 100 - 150. This in turn might increase the reluctance of public transport companies to switch to CNG, thus increasing the risk involved with the capital investment in the conversion centre.

Hence, if the private sector is to be encouraged to venture on this new field of converting diesel buses to CNG operation professionally, on a large scale and on a commercial basis,

government support would be necessary, particularly during the introductory phase. A respective incentive package could, for example, comprise the provision of public land at a nominal price or on a medium-term low-cost leased basis, credit guarantees, soft loans and/or other financing models for the capital investment.

#### **4.4 Bus Operating Costs**

A large-scale conversion of diesel buses to CNG can only be achieved if this is beneficial to the national economy and society in general, as well as profitable for the individual vehicle operator from the micro-economic, i.e., financial point of view. Investment costs for the conversion to CNG must repay in a short time, or else there should be other measures favouring CNG over conventional vehicles. There could, for instance, be restriction on vehicles with high emissions to enter certain city areas, in general or under specified circumstances.

This prohibitive concept, employed for many conurbations in industrialized countries, however, does not yet seem to be accepted (or applicable) in most countries of the ESCAP region. Thus, the supportive, encouraging approach is considered more appropriate in the region at present to pursue the policy of substituting the indigenous and secure energy source of natural gas for imported mineral oil, as well as contributing to the improvement of the environment in the metropolitan areas of many Asian countries.

Annual bus operating costs can be divided into (i) fixed operating costs - comprising primarily annual depreciation (redemption) and interest on capital investment, vehicle licence fee and other taxes, and vehicle insurance; and (ii) variable operating costs - those dependent on the output produced such as costs of fuel, maintenance and operating personnel.

These expenditures plus general and administrative overheads have to be met by revenues from ticket sales. However, if they are not fully covered, as is mostly the case, they are met by subsidies from municipalities or governments, i.e., by the general budget.

Since, at this stage, passengers cannot be expected to accept higher ticket prices for CNG buses, any additional cost due to the conversion of diesel buses to CNG has to be covered by either higher government subsidies to bus operators or by cost savings. In any case, a comprehensive government policy towards the promotion of CNG in road transport is imperative.

The initial effect of CNG operation is an increase in the fixed operating costs due to the additional capital required for the conversion to CNG. These costs must be recovered during the remaining life of the buses. As mentioned earlier, conversion of diesel buses is regularly recommended only for vehicles aged three to maximum five years. The remaining economical service life, and thus the pay-back period of the conversion investment, would then be six to seven years. However, for buses running with a high annual mileage, the life cycle of the engine requires a rebuild after approximately four years, necessitating also replacement of some conversion components. In addition, the CNG storage cylinders have normally to be removed and tested after 3 to 5 years (depending on the safety regulations in a country). Thus, the amortisation period should not be longer than four years. On the contrary, bus operators expect a cost recovery after 2 to 3 years.

Amongst other factors influencing operating costs, the costs involving personnel, insurance and vehicle taxes/fee are rather fixed, although for environmental reasons CNG buses might warrant a preferential treatment over conventional vehicles (like, for example, cars equipped with a 3-way catalytic converter). Maintenance costs are based on the technology applied, and are normally similar for diesel and CNG buses, or if somewhat higher, are mostly balanced by lower lubrication costs. The only cost factor which can compensate for the additional capital costs are reduced annual fuel costs, which depend on the annual consumption and the

price difference between diesel and CNG. The gas price (as the diesel price) is subject to government pricing and taxing policy, with its long-term lower unsubsidized limit determined by the costs for recovery and transmission/distribution.

To summarize: a conversion of diesel buses to CNG will only be viable and attractive to a bus operator, if the additional annual capital (and perhaps maintenance) costs are exceeded by fuel cost savings.

A retrofit conversion of a diesel bus to CNG operation requires an investment of approximately US\$ 5,000 comprising about US\$ 2,400 each for the CNG storage cylinders and other conversion components, and about US\$ 200 for the work (including depreciation etc. of the conversion centre). The cost components may however, vary considerably, depending on the number and size of the cylinders, i.e., the operating range between refuelling, cylinder material, conversion system, engine control technology applied, share of locally produced and imported components, and the amount of customs duty etc. imposed on imported parts.

Applying a cost recovery period of 4 years for equation (1) in Section 4.2, it results in an annual investment cost of US\$ 1,577. Assuming 70,000 km annual duty and 0.33 litres per km of diesel fuel consumption (see Table 3), which is replaced by 0.33 cubic metres of CNG per km, or at the ratio of one to one<sup>1)</sup>, results in a necessary price advantage of US¢ 6.8 for CNG to be viable.

In general, this is expressed by the following equation:

$$\Delta P_{min} = \frac{C}{F_{CNG}} \quad (2a)$$

where:

$\Delta P_{min}$	=	Minimum price differential (advantage) of CNG (per cubic metre) over diesel (per litre)
$C$	=	Annual conversion costs (depreciation and interest)
$F_{CNG}$	=	Annual CNG fuel consumption in cubic metres (assumed equal to the annual diesel fuel consumption in litres)

This equation is however valid only if diesel is replaced by CNG at the ratio of 1:1. The necessary price advantage is then independent of the diesel price level, but varies with the annual duty of the CNG buses. With 50,000 km/year, for example, the necessary minimum price differential would increase accordingly by 40 per cent to US¢ 9.6.

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<sup>1)</sup> The energy consumption (e.g., in MJ/h) of an engine converted to CNG is for physical reasons between 5 to 10 per cent higher than that of the original diesel engine (combined with a 5 to 10 per cent decrease in power output). In actual operation on a city bus, this might, depending on the engine condition and the conversion technology, increase to 25 per cent or more. The energy content of one cubic metre of natural gas, however, which depends on the composition of the gas, is up to 25 per cent higher than that of one litre of diesel, thus compensating more or less for the lower energy efficiency. This results in 1.0 -1.1 cubic metres of CNG being regularly equivalent to, and replacing, 1 litre of diesel.

If due to lower energy content of the natural gas, or less efficient conversion, one litre of diesel will have to be replaced by more than one cubic metre of CNG, the above equation (2a) is modified as follows:

$$\Delta P_{min} = \frac{C}{F_{CNG}} + P_{Di} \times f_e \quad (2b)$$

or

$$\Delta P_{min} = \frac{C}{F_{CNG}} + P_{Di} \times \left(1 - \frac{1}{r_c}\right) \quad (2c)$$

where:

$P_{Di}$	=	Price per litre of diesel
$f_e$	=	Fuel efficiency advantage factor of diesel <sup>2)</sup>
$r_c$	=	Fuel consumption ratio of CNG in cubic metres to diesel in litres

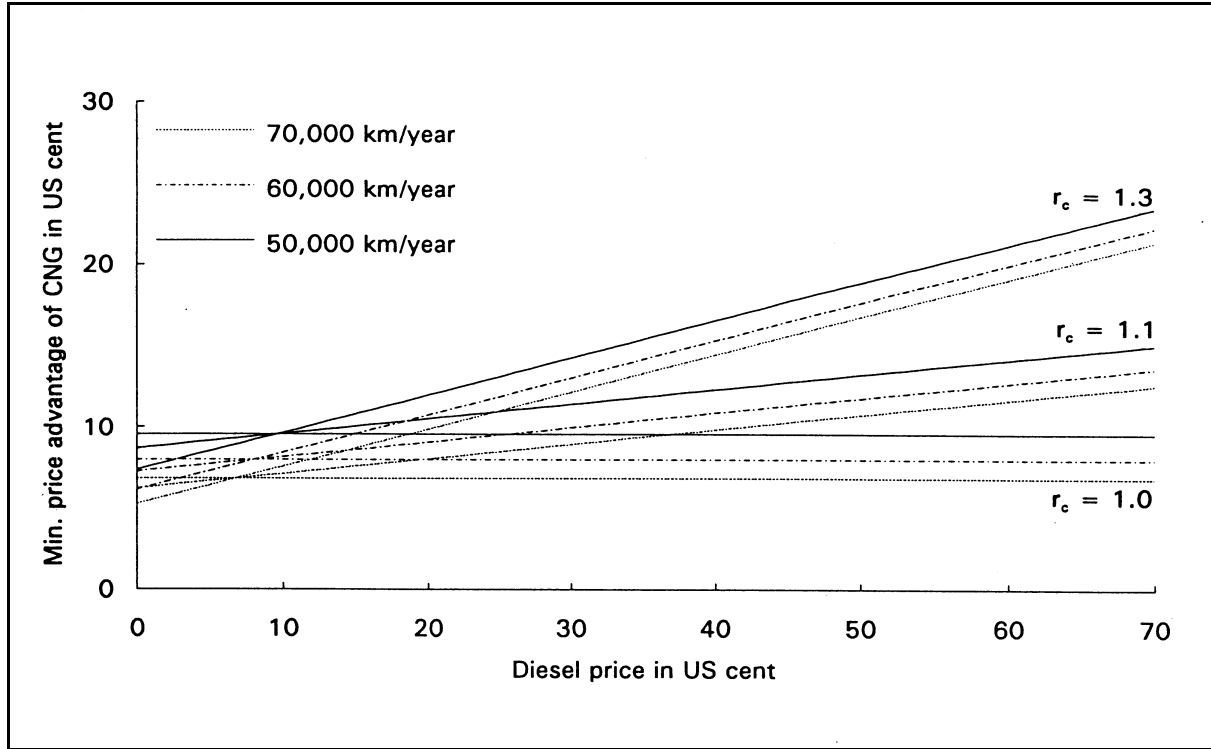
In this case, the necessary minimum price advantage of CNG over diesel depends on the investment in the conversion and the annual CNG consumption (comprising the two components: specific consumption and annual mileage), as well as on the given diesel price level and the surplus consumption of CNG over diesel: the higher the consumption of CNG compared to diesel and the higher the diesel price are, the higher is the price differential required to render CNG a viable option.

The above relationships are illustrated in Figure 5 for different annual duties and fuel consumption ratios. It includes the case of a high surplus consumption of 30 per cent, which reflects the condition of buses/engines, conversion technology and skills prevailing in some countries of the ESCAP region.

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<sup>2)</sup> If, for example, the specific fuel consumption for diesel is 0.33 litres/km, and that for CNG is 10 per cent higher, i.e., 0.363 m<sup>3</sup>/km, then  $r_c = 1.1$  and accordingly

$$f_e = 1 - \frac{1}{1.1}, \quad \text{or:} \quad \left( \frac{0.363 - 0.33}{0.363} \right) = 0.09091$$



**Figure 5: Necessary price advantage of CNG over diesel fuel**

Whereas the price advantage of CNG is certainly of interest to managers of bus companies while considering conversion of diesel buses to CNG, decision makers in government and administration are concerned about its upper limit — both absolute and relative to other fuels, particularly to diesel fuel. The respective function is obtained by transforming equation (2b) into:

$$P_{CNGmax} = \frac{P_{Di}}{r_c} - \frac{C}{F_{CNG}} \quad (3)$$

and

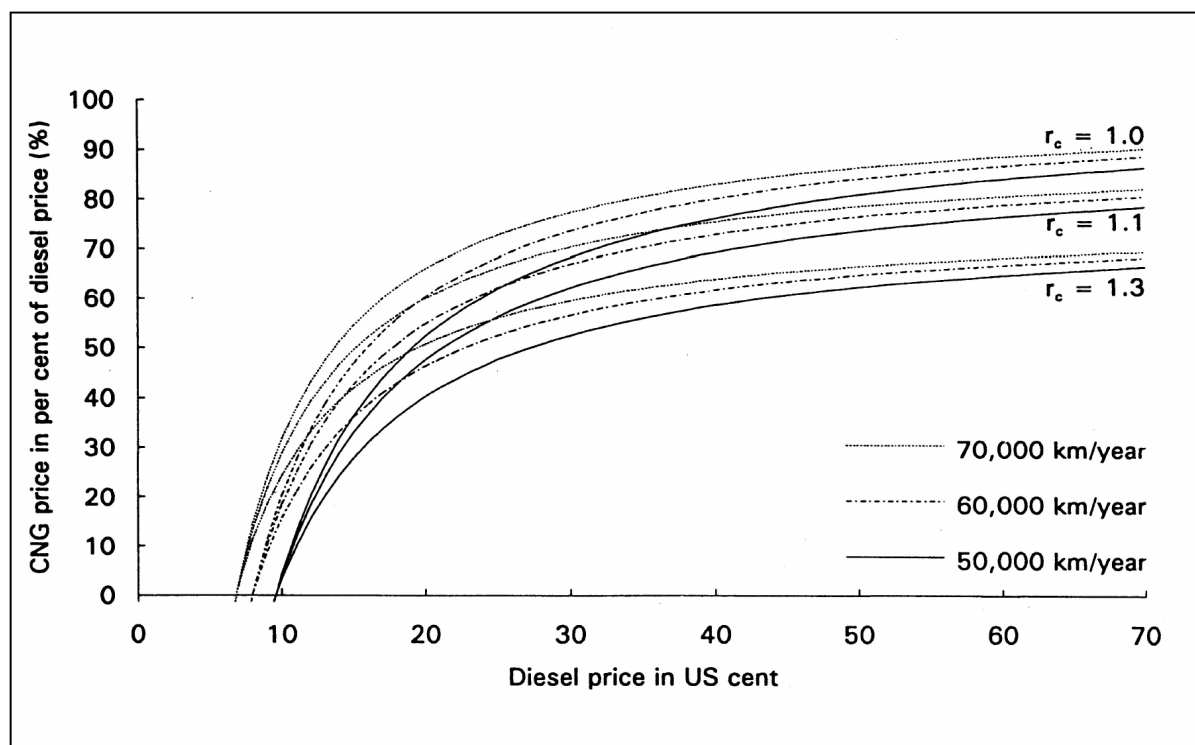
$$RP_{CNGmax} = \frac{P_{CNGmax}}{P_{Di}} \times 100 \quad (4a)$$

$$= \frac{100}{r_c} - \frac{C \times 100}{F_{CNG} \times P_{Di}} \quad (4b)$$

where:

- $P_{CNGmax}$  = Maximum feasible CNG price per cubic metre (in absolute monetary terms)
- $RP_{CNGmax}$  = Maximum feasible CNG price per cubic metre relative to the diesel price per liter (in per cent)

Figure 6 illustrates this relationship for different annual duties and fuel consumption ratios for annual conversion costs of US\$ 1,577, corresponding to an average conversion investment of US\$ 5,000 (based on the stated assumptions).



**Figure 6: Relative maximum feasible CNG price as a percentage of the diesel price**

The graphs in Figure 6 represent cost equivalency curves or break-even curves defining CNG price as a percentage of the given diesel price for which, under certain given circumstances, conversion costs are fully compensated for by fuel cost savings. All CNG prices on or below the graphs represent viable alternatives for the bus operator, whereas CNG prices above the graphs will result in overall cost increases to the operator and render any CNG programme not feasible.

It is clear that in order to compensate for the additional cost to the bus operator by converting diesel buses to CNG through the fuel price, the price for CNG has to be considerably lower than the diesel price. When diesel price levels are low (due to low taxation or even subsidies), as in many ESCAP countries (between US¢ 15 - 30 per litre), the maximum price for CNG per cubic metre should not exceed 50 - 60 per cent of the diesel price. Only if diesel prices are higher (due to higher taxes), as in Europe, a price for CNG of up to 75 or 80 per cent of the diesel price would be feasible.

The long-term lower limit for an unsubsidized CNG price, defined through the costs for recovery and transmission/distribution plus profit margin (albeit without taxes) is about US¢ 12 - 16 per cubic metre, depending on the conditions in a country. Based on the relationship between CNG and diesel prices (Figure 6), a necessary minimum diesel price of approximately US¢ 20 - 27 is a prerequisite to render any CNG programme a success.

The importance of the relationship between the CNG and the diesel price might be illustrated by an example based on preliminary data of the on-going monitoring phase of the CNG

demonstration project in Karachi. In this particular case, the conversion cost is approximately US\$ 3,500 with the break-down given in Table 4.

This indicates that with an annual investment cost of US\$ 1,104 and yearly maintenance cost of US\$ 80, the bus operator has to save more than US\$ 1,184 by substituting CNG for diesel.

Cost Item	US Dollars
1. Material:	
- 5 cylinders with 90 litres capacity	2,000
- 1 cylinder with 60 litres capacity	350
- imported CNG components	600
- local CNG components	350
2. Work (including overhead)	200
<b>TOTAL</b>	<b>US\$ 3,500</b>

**Table 4: Breakdown of the total cost for conversion of a diesel bus to CNG**

First results from a particular conversion type in the Karachi project show a consumption of 0.29 litres/km with diesel, and 0.38 m<sup>3</sup>/km with CNG operation. Based on an annual mileage of 60,000 km, 17,400 litres of diesel will in this case be replaced by CNG. Given an actual diesel price of US¢ 20.4 per litre, the US\$ 3,550 previously spent on diesel will have to cover the total annualized conversion costs of US\$ 1,184 as well as the fuel cost for CNG. As a result, the total annual CNG bill must not exceed US\$ 2,366 (= US\$ 3,550 - US\$ 1,184) which results in a maximum feasible CNG price of US¢ 10.4 per cubic metre or 50.9 per cent of the diesel price. This corresponds to the actual price levels in the project, with the current CNG price fixed at approximately half of the diesel price.

However, it has been proposed to raise the CNG price to at least 70 per cent of the diesel price. This would result in overall higher operating costs for CNG buses and render the conversion of diesel buses to CNG unattractive, despite being profitable for the conversion of gasoline vehicles. Theoretically, since the decisive factor is not the absolute price but the price difference between CNG and diesel, the prices for both could be increased until a sufficiently great price advantage for CNG is achieved. However, under given circumstances with a consumption ratio of more than 1.3, a CNG price level of 70 per cent would always be above the respective break-even curve and never be feasible (Figure 6).

Given the present situation in countries of the ESCAP region with natural gas resources, in most cases the price difference between CNG and diesel fuel is insufficient to recover the conversion costs through fuel cost savings with CNG operation. Under these circumstances, voluntary and sustained participation of fleet operators in a CNG conversion programme cannot be expected. In order to change this situation, the following measures would essentially be required:

1. The price of gas has to be fixed clearly below the corresponding prices of conventional fuels. This can be achieved by lowering the taxes on natural gas.

2. Import duties or other taxes and fee imposed on CNG vehicles or vehicle components should favour natural gas vehicles. In this regard, preferential treatment is justified in view of the positive impacts on the environment by natural gas vehicles.

Both measures are, however, interlinked: lower taxation on CNG vehicles and components require a relatively smaller price differential between diesel fuel and CNG, i.e. a smaller tax reduction on natural gas, whereas without abolition or reduction of CNG vehicle/equipment taxes a higher price advantage of CNG would be required for its compensation.

Both components of encouragement, which are necessary from the financial point of view of the bus operator, will have consequences for the national budget. An analysis of the net impact on the national budget is outlined in the following account.

#### **4.5 National Budget**

Revenues from sales of mineral oil products and natural gas represent quite a significant source of income for the government in many countries of the ESCAP region. In Pakistan, for example, diesel fuel consumption in the transport sector amounted to approximately 4.2 million tons in 1991-92, resulting in government revenues from excise duty and development surcharge of about US\$ 100 million. Reduction in diesel fuel consumption, due to increased use of CNG in road transport, would definitely reduce this source of income. Based on sample calculations presented in Section 4.1, government revenues from diesel fuel would drop by more than US\$ 2 million per year. Such a negative fiscal impact might not be considered desirable, despite an overall positive impact of a CNG programme on the national economy, resulting possibly in increased tax revenues from secondary sources, and intangible benefits such as reduced noise and air pollution.

On the other hand, one litre of diesel is regularly replaced by approximately one cubic metre of natural gas. Assuming, the same amount of duties, taxes etc. levied on natural gas as on diesel fuel, the net impact on the national budget through the conversion of diesel vehicles to CNG operation would actually be zero, because one source of revenue is merely substituted by another of the same volume.

In many countries, however, government taxes on natural gas are usually higher than those on diesel. Therefore, the replacement of diesel by CNG would, accordingly, lead to higher revenues which could be utilized to fund incentives such as the abolition of import duties on CNG equipment in a CNG conversion programme.

The above considerations are valid only when current retail prices for diesel and CNG provide a sufficiently high price advantage for CNG vehicle operators and gas suppliers. Otherwise, the existing pricing/taxation structure will have to be changed either by increasing taxes on diesel or by reducing taxes on natural gas, because the decisive factor is the price difference between CNG and diesel rather than the actual price of CNG.

It is important to know that if existing taxes on natural gas are higher than those on diesel, any reduction of gas taxes down to the level for diesel would still result in a positive or neutral fiscal balance. A reduction of gas taxes below the diesel level would, however, have a negative impact on the budget.

It is, therefore, clear that if existing gas taxes are lower, no changes in the tax system would be required, since the lower production cost of natural gas compared to diesel fuel provides already the necessary price difference to render CNG attractive. Only in the exceptional case that diesel prices need to be increased, a corresponding increase of diesel taxes would be necessary - with a resulting positive fiscal impact. Any such increase would in most cases need to be only



marginal, and is not expected to have any repercussion on the transport industry or the national economy in general.

To summarize: if taxation on natural gas is comparative to that on diesel fuel, the conversion of diesel buses to CNG would in most cases be without any major consequence to the national budget. The impact on a particular country will, however, need to be assessed on the basis of on the given situation.

#### **4.6 Quality of Life in Conurbations**

An improvement of air quality by conversion of vehicles to CNG is without any direct, tangible impact on the economy of a nation, and is experienced primarily as an improvement in the quality of life in conurbations.

However, it has been established that permanent exposure to air pollutants emitted by gasoline and diesel engines leads to an increased susceptibility to diseases such as bronchitis, asthma and cardiovascular conditions. Children and the elderly are particularly affected.

These diseases cause expenses for medical care and are also responsible for the loss of production output. Both factors have negative effects in micro and macro-economic terms. On the other hand, the use of CNG as an alternative fuel to diesel results in health benefits, including reduced risk of cancer, since particulate matter is practically eliminated from exhaust gases.

Further economic damage by air pollution emerges from premature decay of buildings in cities and adverse effects on crops and forests, even in areas far away from conurbations. Diesel fuel contains sulphur which, during combustion, forms sulphur dioxide and sulphur trioxide which eventually form sulphuric acid in the atmosphere, contributing to the problem of "acid rain". Natural gas, on the other hand, contains no sulphur and thus has no sulphur emissions.

The global effects of „greenhouse-gas“ emissions by internal combustion engines are still to be fully understood. In any case, the reduction through the use of CNG represents a contribution to minimize expected future global climatic changes with devastating effects particularly for the coastal regions of the world including the Pacific Island Countries in the ESCAP region. Even if the economic impact cannot be determined, ethics alone demands of each individual any action considered conducive to preserve the natural basis of life on earth for future generations.

In physical terms, however, the impact of the substitution of diesel fuel by CNG can be determined and quantified. In Pakistan, for example, if 15 per cent of all urban buses (or 4,200 city buses) would be operating on 100 per cent CNG and with a three-way catalytic converter, the following annual reductions in exhaust pipe emissions could be achieved:

- 265 tons of nitrogen oxides;
- 55 tons of unburned hydrocarbons;
- 69 tons of carbon monoxide;
- 18 tons of sulphur dioxide;
- 18 tons of carbon dioxide; and
- 328 tons of particulates.

However, these reductions are possible only under the technical conditions stated earlier. With dual fuel engines as a first step of a conversion programme, reductions will be considerably lower (especially nitrogen oxides, carbon monoxide and unburned hydrocarbons) because of the

use of about 30 per cent diesel fuel for ignition, and due to the fact that a catalytic converter cannot be applied with this engine concept.

#### **4.7 Summary**

The overall impact of an increased use of natural gas as fuel on the national economy can be considered as positive. However, without governmental support, large-scale use of CNG driven vehicles cannot be achieved due to the financial situation of operators in many countries in the ESCAP region. The critical phase of the introductory period are the first few years, when considerable governmental assistance to set up the supply infrastructure and to offer incentives for potential operators might be necessary. During this initial phase, the positive impact on the balance of trade and the economic effects of an indigenous natural gas industry are not yet visible.

Preparatory activities by the state to create favourable conditions for the use of CNG vehicles are necessary. These efforts pay off in the medium term, provided a consequent and comprehensible CNG policy is pursued. The establishment of respective national programmes to promote the use of CNG in road transport, incorporating the experience of developed as well as ESCAP developing countries with domestic natural gas resources, is thus an essential prerequisite of a successful and lasting substitution of diesel fuel by natural gas.

## II. GUIDELINES FOR THE CONVERSION OF DIESEL BUSES TO CNG

Substitution of diesel fuel by CNG in urban buses (and trucks) is particularly advantageous because these vehicles on one hand have high specific fuel consumption and high mileage, and on the other hand, need only few centrally located filling stations in view of their limited range of operation.

The economic and ecological benefits of CNG driven urban buses are illustrated by the following examples:

- The conversion of one diesel bus to CNG saves about 145 barrels of petroleum annually at average operating conditions. Given a petroleum price of US\$ 20 per barrel, this results in foreign exchange savings of US\$ 2,900 per bus per year;
- CNG operation of buses leads to a considerably reduced output of, in particular, visible particulate emissions (black soot) which, besides being a nuisance, is damaging to health. Depending on the specific type of conversion, a reduction of up to 95 per cent from approximately 80 kg to only about 4 kg per vehicle per year is possible;
- Engine noise is reduced by up to 5 dBA which corresponds to a 50 per cent reduction in noise emission.

However, these potential macro-economic and ecological benefits to the national economy and the society in general can only be fully realized through a large-scale conversion programme based on micro-economic advantages for the bus operator. This means that for a successful CNG programme, the conversion of diesel buses to CNG has to be attractive, i.e. profitable, to the operator. To create such favourable conditions, the following policy guidelines should be pursued:

### (1) The price of CNG has to be considerably lower than that of diesel

In comparison with diesel driven vehicles, CNG buses might, depending on the conversion concept and the condition of the vehicle, have a higher fuel consumption (normally, however, one litre of diesel can be replaced by approximately one cubic metre of gas) and may require higher maintenance expenses (although it is likely to be slightly lower, e.g. in terms of lubricating oil, due to lower wear of gas engines). In any case, however, additional investment for CNG cylinders and CNG conversion equipment is system-immanent. In order to compensate for this, the price of CNG has to be considerably lower than that of diesel fuel.

When diesel prices (due to low tax rates or even subsidies) are low, i.e. in the range of US\$ 15 - 30 per litre, the maximum price for CNG should not exceed 50 - 60 per cent of the diesel price. Only if diesel prices are high (e.g. in Europe), CNG prices up to 75 or 80 per cent of the diesel price could be feasible.

The lower limit for an un-subsidized CNG price, defined through the cost for recovery and transmission/distribution plus profit margin (albeit excluding taxes), is about US\$ 12 - 16 per cubic metre depending on the conditions in a specific country. This requires a minimum diesel price of US\$ 20 - 27 per litre for a successful CNG programme.

## **(2) Taxes on CNG have to be comparative to those on diesel**

In most countries of the world, fuel prices are either directly regulated by governments or considerably determined by import duties or other taxes. The level of taxation is based on certain policy considerations. In several countries of the ESCAP region, for example, taxes on diesel, essentially the fuel for the transport industry, are much lower than on gasoline which is mostly used by private cars. The objective is to support the national economy through low transport prices. Since natural gas as yet is only marginally used in road transport, existing taxation, based on other considerations, is in many cases higher than on diesel oil.

To achieve the necessary price differential between CNG and diesel (as described above), taxes on CNG have to be comparative to those on diesel, thus reflecting the generally lower production cost of natural gas as compared to diesel. This would have little or no consequence to the national budget because diesel is merely substituted by CNG. However, if taxes have to be increased on diesel to provide a price advantage for CNG, the additional revenues could provide the funds for a CNG incentive package.

## **(3) A CNG conversion programme has to be supported by direct Government assistance**

For refuelling CNG buses, one CNG station is typically needed for approximately 120 - 150 city buses. This would require foreign exchange investment of about US\$ 200,000 per station exclusive of import duties. After adding the costs for local construction, land acquisition and connection of the station to the pipeline network of about US\$ 100,000 - 150,000, the high investment cost (even excluding import duties) would be a burden for the station operator, especially during the initial phase of a CNG programme when the demand is not sufficient to achieve a satisfactory cost coverage over the gas price.

Since, however, a successful CNG programme depends on the voluntary cooperation of all parties involved, it has to be attractive to the CNG station operator as well. Thus, an incentive package by the government is necessary, comprising abolition of import duties (preferably also on conversion components) and soft loans or other financing models for capital investment.

## **(4) Conversion of diesel buses to CNG should preferably be confined to vehicles up to the age of three years**

An efficient conversion is possible only with buses in good technical condition. Therefore, conversion programmes should preferably be confined to vehicles up to the age of three years. In case of older buses in technically unsatisfactory condition, a considerably higher consumption of gas (as well as poor benefits to the environment) could be expected. The conversion cost may, therefore, never be recovered or only after an unattractive period of time.

**(5) As a first step, conversion should be carried out in dual fuel technology**

From the overall economic and ecological points of view, optimum benefits could be achieved with new vehicles equipped with ex-factory CNG engines. However, despite lower diesel substitution rate and, accordingly, reduced environmental benefits, as a first step, the conversion of existing buses to dual fuel technology, preferably with electronically controlled gas supply and pilot injection of diesel, is the best alternative. The conversion of diesel engines to dedicated single fuel CNG engines, although more favourable in principle, is associated with some technical problems which may require higher skills to overcome than usually available.

**(6) A CNG conversion programme has to be accompanied by a technical training programme**

The conversion of diesel buses to CNG requires higher qualification of technical personnel than in the case of maintenance of diesel engines. In order to achieve a high domestic output from the conversion programme, technical training programmes should be developed and conducted with the assistance of foreign experts, in the initial phase. However, it is imperative to enhance local capacities in order that the training programmes and CNG conversions become self-sustained, and are carried out locally (without external assistance) on a continuous basis following the initial phase.

**(7) Country specific CNG demonstration projects should be initiated and supported by the Government**

The success of a CNG programme depends primarily on the widespread acceptance of the programme by potential operators who need to be convinced of the advantages of CNG operation. For this purpose, the government should initiate and support projects to create awareness of the programme and to demonstrate that the operation of CNG buses is technically reliable and economically attractive. Such demonstration projects could also address specific conditions in individual countries which could not be included in these general recommendations.

### **III. CONCLUSION**

Due to its high dependency on mineral oil products, the road transport sector offers great potential for the substitution of imported petroleum and refined petroleum products by the domestic and environment-friendly natural gas as an energy source. The increased use of natural gas, in the form of CNG, in road transport thus helps to improve the balance of payments, the security of energy supply, and concurrently the environment, particularly in metropolitan areas.

From the technical point of view, natural gas as a substitute fuel for gasoline engines implies no problems at all. In the case of diesel engines, however, they have to be modified (converted) to CNG combustion. It is, in principle, applicable to all countries of the ESCAP region with natural gas resources, irrespective of their state of economic and technical development.

Substitution of diesel fuel by CNG in urban buses offers a particular advantage in view of their high specific fuel consumption combined with high annual mileage, and because they require only few centrally located CNG refuelling stations due to their limited and regular operating patterns. Thus, large captive fleets of city buses are the primary target for the introduction of a CNG conversion programme.

The principle driving force in the successful implementation of a CNG conversion programme is user economics. There must be sufficient direct operating cost savings for vehicle operators to consider changing from the familiar diesel bus operation to the new CNG fuel. In addition, CNG station operators and gas distribution companies must also be able to profit from this new venture. If one of these groups does not have a satisfactory incentive to participate in the CNG programme, it is likely that the programme will fail.

It is therefore essential for a successful CNG conversion programme, that the price of CNG is considerably lower than that of diesel fuel to compensate for the necessary additional investment for the conversion as well as for the CNG supply infrastructure. A clear-cut conducive policy with corresponding fuel pricing/taxation structure is the decisive factor for the target markets to respond to a CNG programme. In addition, an incentive package comprising, e.g., launching of demonstration projects, introduction of soft loans or other financing models for capital investment in the CNG supply infrastructure, reduction in "red tape" for approval/licensing of CNG equipment, and abolition of import duties on CNG stations and conversion equipment, would convey a clear message to all parties involved, including equipment and vehicle manufacturers, with regard to the government's commitment to the CNG conversion programme.

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