Division 44
Environment and Infrastructure
Sector project "Transport Policy Advisory Service"

Sustainable Transport:
A Sourcebook for Policy-makers in Developing Cities
Module 4d

Natural Gas Vehicles

– revised November 2005 –

Deutsche Gesellschaft für
Technische Zusammenarbeit (GTZ) GmbH

commissioned by:

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and Development

Overview of the sourcebook

Sustainable Transport: A Sourcebook for Policy-Makers in Developing Cities

What is the Sourcebook?

This *Sourcebook* on Sustainable Urban Transport addresses the key areas of a sustainable transport policy framework for a developing city. The *Sourcebook* consists of more than 20 modules.

Who is it for?

The *Sourcebook* is intended for policy-makers in developing cities, and their advisors. This target audience is reflected in the content, which provides policy tools appropriate for application in a range of developing cities.

How is it supposed to be used?

The *Sourcebook* can be used in a number of ways. It should be kept in one location, and the different modules provided to officials involved in urban transport. The *Sourcebook* can be easily adapted to fit a formal short course training event, or can serve as a guide for developing a curriculum or other training program in the area of urban transport. GTZ is elaborating training packages for selected modules, being available since October 2004.

What are some of the key features?

The key features of the *Sourcebook* include:

- A practical orientation, focusing on best practices in planning and regulation and, where possible, successful experience in developing cities.
- Contributors are leading experts in their fields.
- An attractive and easy-to-read, color layout.
- Non-technical language (to the extent possible), with technical terms explained.
- Updates via the Internet.

How do I get a copy?

Please visit http://www.sutp.org or http://www.gtz.de/transport for details on how to order a copy. The *Sourcebook* is not sold for profit. Any charges imposed are only to cover the cost of printing and distribution. You may also order via transport@gtz.de.

Comments or feedback?

We would welcome any of your comments or suggestions, on any aspect of the *Sourcebook*, by e-mail to transport@gtz.de, or by surface mail to:

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Further modules and resources

Further modules are anticipated in the areas of *Financing Urban Transport* and *Benchmarking*. Additional resources are being developed, and an Urban Transport Photo CD-ROM is available.

Modules and contributors

Sourcebook Overview and Cross-cutting Issues of Urban Transport (GTZ)

Institutional and policy orientation

1a. *The Role of Transport in Urban Development Policy* (Enrique Peñalosa)
1b. *Urban Transport Institutions* (Richard Meakin)
1c. *Private Sector Participation in Transport Infrastructure Provision* (Christopher Zegras, MIT)
1d. *Economic Instruments* (Manfred Breithaupt, GTZ)
1e. *Raising Public Awareness about Sustainable Urban Transport* (Karl Fjellstrom, GTZ)

Land use planning and demand management

2a. *Land Use Planning and Urban Transport* (Rudolf Petersen, Wuppertal Institute)
2b. *Mobility Management* (Todd Litman, VTPI)

Transit, walking and cycling

3a. *Mass Transit Options* (Lloyd Wright, University College London; Karl Fjellstrom, GTZ)
3b. *Bus Rapid Transit* (Lloyd Wright, University College London)
3c. *Bus Regulation & Planning* (Richard Meakin)
3d. *Preserving and Expanding the Role of Non-motorised Transport* (Walter Hook, ITDP)
3e. *Car-Free Development* (Lloyd Wright, University College London)

Vehicles and fuels

4a. *Cleaner Fuels and Vehicle Technologies* (Michael Walsh; Reinhard Kolke, Umweltbundesamt—UBA)
4b. *Inspection & Maintenance and Roadworthiness* (Reinhard Kolke, UBA)
4c. *Two- and Three-Wheelers* (Jitendra Shah, World Bank; N.V. Iyer, Bajaj Auto)
4d. *Natural Gas Vehicles* (MVV InnoTec)
4e. *Intelligent Transport Systems* (Phil Sayeg, TRA; Phil Charles, University of Queensland)
4f. *EcoDriving* (VTL; Manfred Breithaupt, Oliver Eberz, GTZ)

Environmental and health impacts

5a. *Air Quality Management* (Dietrich Schwela, World Health Organisation)
5b. *Urban Road Safety* (Jacqueline Lacroix, DVR; David Silcock, GRSP)
5c. *Noise and its Abatement* (Civic Exchange Hong Kong; GTZ; UBA)

Resources

6. *Resources for Policy-makers* (GTZ)

Module 4d

Natural Gas Vehicles

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Reinhard Kolke of the Umweltbundesamt (German Federal Environment Agency) reviewed the material for inclusion in the *Sourcebook*, and recommended including the original material, without modification, as although the original publication is from 2000, the information remains 'state of the art' in 2002.

Some additional case study material has been included, focusing on developing countries.

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New CNG buses on the Brisbane Busway, January 2003

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Foreword to the orginal document

This *Decision Makers' Guide to Natural Gas Vehicles* is a European Commission-funded project that is a companion document to the *Natural Gas Vehicles Equipment Guide*. Used on its own, this Decision Makers' Guide provides basic but essential information required by public officials or commercial fleet owners considering using natural gas vehicles (NGVs) as part of their vehicle fleet mix.

The authors have attempted to present answers to some of the most basic questions asked about NGVs. But, with decision making in mind, there is fundamental, easy-to-read information that addresses issues about:

- Vehicle characteristics, including conversions and factory produced NGVs
- The best vehicle applications appropriate as NGVs
- Economics and availability of vehicles
- Fuelling approaches and technologies
- Special considerations for installing fuelling station equipment
- Safety for vehicles, fuelling, and operations (such as in underground parking situations)
- Assistance that may be available to provide detailed guidance and advice about their NGV choices and
- Specific and general sources of information that is readily available.

When it comes to selecting specific equipment—vehicles or fuelling stations—the companion *Natural Gas Vehicles Equipment Guide* will be useful to get a better understanding of what is available and from whom to purchase the equipment. Together these two documents should provide enough guidance for the users to know whether or not to continue to pursue the NGV option.

Once a decision is made to move further, the companies identified as sources of information or products should be contacted so that a detailed profile of your NGV programme can be created. This will enable your to determine the specific economics of your situation, the emissions reduction potential, and the many aspects about developing a fuelling station, if that will be required.

March 2000

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1. Vehicle fleet profile/applications

Companies owning multiple vehicles—fleets—that return each night to one central depot have been a traditional form of vehicle profile that is economically attractive for natural gas. In most countries the Natural Gas Vehicle (NGV) fuelling infrastructure is much less developed than for petrol/diesel, therefore, fleet operators are the best target for the early installation of a fuelling infrastructure. The more public access fuelling stations are installed, the more attractive natural gas will become to the full range of fleets and commuter vehicles. This has been the pattern in countries such as Italy, with 420,000 vehicles and 500 fuelling stations and Argentina, with over 1,400,000 vehicles and over 1,400 fuelling stations.

Many cities are also becoming interested in locally produced biogas as a vehicle fuel. Biogas is produced from organic waste as a by-product of sewage treatment, and has long been used as a domestic heating fuel. In purified form it can be used in any vehicle designed to run on methane gas.

1.1 Original equipment manufacturers and conversions

Original equipment manufacturers

More and more original equipment manufacturers (OEMs) are making factory-built NGVs of different kinds. In fact, today more than 40 manufacturers world-wide are producing NGVs. These vehicles are either dedicated (running on natural gas only) or are bi-fuel (running on natural gas or petrol). The dedicated vehicles are optimised for natural gas to take advantage of the high octane rating—about 130—compared to petrol at 80–100. These vehicles are fully engineering by the manufacturer and, as such, typically perform to the best of the manufacturer's standards, similar to a petrol or diesel vehicle. These NGVs are fully warranted so that if a breakdown occurs, the vehicle can be returned to the manufacturer for servicing and maintenance.

Some OEMs have programmes with companies that do factory-quality conversions to natural gas, but that are sold as factory-built vehicles. These vehicles are treated as if they came off the factory assembly line, and are fully warranted as long as the service schedules of the manufacturer are followed.

Conversion to natural gas

Most NGVs on the road today are petrol vehicles converted to run on natural gas or petrol by a private company once the vehicle has left the manufacturer's factory. There are many national and international standards that must be met when converting a vehicle to run on natural gas (please see section 7). This provides some assurance that if the regulations are followed by the conversion company, there should be few problems. This also offers some forms of consumer protection if something should go wrong due to actions by the conversion company.

Bi-fuel conversions of petrol vehicles: A bi-fuel conversion system and high-pressure fuel tank are added to an existing petrol vehicle. The vehicle can operate either on natural gas or on petrol. When the natural gas has been used up, the driver flips a switch (or with some systems it happens automatically) and the vehicle switches to petrol. This can be done while the vehicle is in operation or is idle. The natural gas equipment can also be removed from the vehicle at the time of resale and returned to its normal petrol operation if desired.

Dual-fuel conversions of diesel vehicles: Some diesel engines are converted using a *dual fuel* system; that is, they run on a combination of natural gas and diesel. When the engine is idle, it runs on 100% diesel. As soon as the vehicle starts driving, and as it builds up speed, increasingly more natural gas is injected into the engine, up to about 80% gas and 20% diesel. In a diesel engine, the fuel is ignited through the heat of combustion (instead of a spark plug) the diesel fuel acts as a 'pilot' fuel to ignite natural gas in the engine.

Dual fuel performance and emissions vary depending upon operating conditions and the sophistication of the control system. Systems developed in the 1980s tended to 'fumigate' the natural gas into the engine through the air intake manifold. Later developments used replacement diesel injectors that instead injected natural gas into the diesel cylinder, and thus improved performance and emissions. New developments in dual fuel systems that are

Best available technology for CNG

For environmental reasons the best available technology for CNG are mono-fuel CNG engines with catalytic converter technologies. This allows the best optimisations on fuel consumption and emissions. While stoichiometric concepts (Lambda = 1) allow the lowest emission performance in comparison to diesel engines (app. –85% nitrogen-oxides, no particulates), mono-fuel lean burn concepts can reduce fuel consumption further. For lean burn concepts the manufacturer should guarantee that the emission performance offers low NO_x-emissions and an efficient oxidation catalytic converter reduce hydrocarbon emissions substantially.

computer controlled, so-called direct injection systems, have overcome some of the problems associated with previous generations of the technology. These systems are, however, limited to a small number of engines and manufacturers. Depending upon the technology, and the manufacturer, dual fuel diesel/natural gas engines can offer economical alternatives to purchasing a new vehicle and/or 'repowering' (replacing) an existing diesel engine.

Practical tips when considering converting a vehicle

- ***What kind of vehicles can be converted to run on natural gas?***

Almost any type of petrol vehicle can be converted, mostly to bi-fuel so that it runs on natural gas or petrol. These include: passenger cars, taxis, police cars, small buses, vans and delivery service vehicles. Off-road vehicles, including airport tugs, fork lifts, ice-cleaning machines, and even boats and trains are candidates for conversion to natural gas.

Many diesel vehicles can be converted but it is more complicated than converting a petrol engine. Most diesel conversions tend to be large vehicles such as garbage trucks or buses. (See above, dual fuel conversions)

- ***It is better to convert newer vehicles rather than old ones.***

Depending upon the annual kilometres you travel and how much fuel you consume, the payback period may be 2–5 years (Please refer to 4). This favours converting newer vehicles. Sometimes complete overhauls of old vehicles would be recommended prior to conversion, to ensure the vehicles are in good working order. Remember, a car running poorly on petrol also will run poorly on natural gas.

- ***Convert the vehicles that tend to travel many kilometres per year.***

Payback of the natural gas system will depend upon the price differential between natural gas and petrol/diesel. Vehicles that travel high kilometres each year will achieve a quicker payback than vehicles that do not travel too much.

- ***Consider the way a vehicle is used before converting it.***

Vehicles that travel more than about 160–175 km per day may require an additional fuel tank to increase the vehicle range. The vehicle should be sizeable enough to include a second fuel tank.

Petrol engines converted to natural gas tend to lose about 8–10% power. This is because natural gas is introduced into the cylinder as a vapour, which replaces about 8–10% of the oxygen in the cylinder head, thus reducing power. Larger engines (at least more than 1 litre) converted to natural gas tend to exhibit less of a power loss than smaller engines.

Fig. 1-1
MAN natural gas bus in operation in Augsburg, Germany.

In the absence of a complete fuelling infrastructure, converting fleet vehicles that return to one base each night is a sound, economical approach.

1.1.1 Urban buses

The urban bus is a very popular candidate to run on natural gas (25% of new buses in the U.S. and in France run on natural gas).

- The vehicle uses a lot of fuel and the more diesel fuel can be replaced by natural gas, the quicker the payback will be achieved.
- City buses travel in high density, congested (with people and buildings) areas of town.

Fig. 1-2
Renault natural gas bus in operation in Poitiers, France.

Particulates and other emissions come into contact with more people living in the inner cities than buses running in areas with reduced populations and more open space.
- Stop-start driving patterns of buses increase pollution potential, so natural gas can help reduce visible smoke, soot, and particulates.
- Large, high compression bus engines result in good driving performance due to the 130 octane rating of natural gas.

Many buses run 100% on natural gas. Most world-wide bus manufacturers make a version of their products running on natural gas, so it is relatively easy to order a bus to everyone's specification. Buses (and other diesel-cycle engines) may also be converted to run on natural gas. Some of these tend to be *dual-fuel* conversions.

What special considerations are there when making a decision to use natural gas buses?

- *The weight of natural gas fuel cylinders* - with enough on-board fuel storage capacity will take up about 17% of the vehicle's carriage weight. If the vehicle becomes too heavy it reduces the number of standing passengers.
- *The fuel efficiency on natural gas buses is not as good as diesel engines.* Reports of 10–15% decreased fuel efficiency are common. When a vehicle shows much higher natural gas fuel consumption (25–40%) then drivers should be monitored and retrained so that they are not over-driving the vehicle and reducing fuel efficiency.
- *Maintenance garages* normally have been set up to handle diesel fuel and vehicles. Since natural gas is lighter than air and dissipates upward, adequate ventilation is required at the ceiling-level in workshops. Sometimes explosion proof lights may be required.
- *Many bus operators demand quick filling as is the case with diesel.* Natural gas buses can be filled in the same time as diesel buses, but large compressors are required to ensure an adequate flow and capacity. Some bus companies use a combination of slow (overnight) filling as well as fast fill. This is possible depending upon the bus operator and his ability to be flexible when incorporating natural gas buses into his fleet (Please refer to section 2).

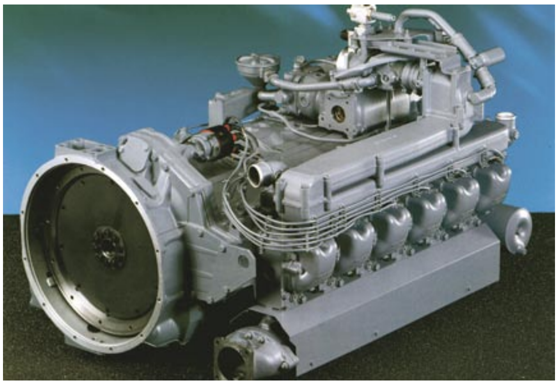


Fig. 1-3
CNG engine, MAN, capacities are available 170 kW and 228 kW (lean burn technology).

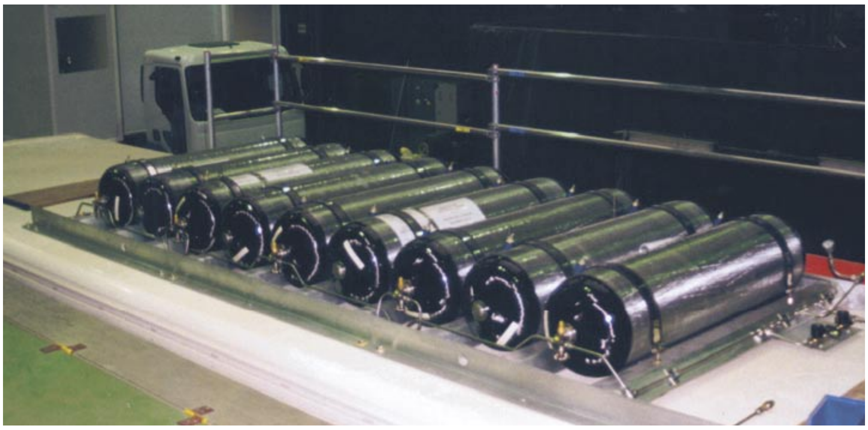


Fig. 1-4
Tank storage on the roof of a bus

1.1.2 Minibuses

The minibus, typically, is used as a personal shuttle for small groups not requiring a large urban vehicle. Hotels and car rental companies typically use minibuses for short haul (but continual) service. They can be excellent candidates for driving on natural gas because of the large amount of fuel they tend to consume if they are in constant use. A wide variety of minibuses are available from the manufacturers, many of whom use other companies' standard natural gas engines and install them in their own chassis and minibus shells.

Fig. 1-5
Mercedes Benz minibus in operation in Roma, Italy.

Fig. 1-6
ERF Garbage truck type EC 12.30 TMU 6x2, 26 metric tonnes, in operation in Ixelles, dedicated Perkins natural gas engine, type: Eagle 340 TxSi

1.1.3 Garbage trucks

Garbage trucks are popular vehicles to drive on natural gas. They are high polluting, fuel consuming and noisy vehicles that are centrally fuelled. Natural gas octane rating results in a much quieter sound from the diesel engine. As many garbage trucks begin early in the morning, noise pollution is an important factor.

The weight of storage cylinders on board the vehicle typically reduces the vehicle's carriage weight by about 17%, which is a cause of concern for the waste management industry. Experience has shown that the selection of suitable vehicles with regard to load and axle width is difficult. Therefore, most of the natural gas garbage trucks are specially manufactured vehicles which leads to maintenance and repair problems. For example, the London Borough of Sutton has repair problems with frequent breakdowns coupled with unsatisfactory service support. Improved heavy duty vehicles are currently under development and the respective cities are awaiting results.

Some garbage trucks run on biogas made from waste materials (human, agricultural, etc.). This offers an opportunity to have an 'environmentally closed loop' garbage truck whereby the 'fuel' (waste material) is processed into natural gas or biogas which, in turn, fuels the truck.

Fig. 1-7
DAF Garbage truck in operation in Haarlem, The Netherlands, converted by Scania

The biogas garbage trucks running in Stockholm are an example for such closed energy loops. Stockholm originally developed biogas facilities to reduce greenhouse gas emissions from rubbish dumps and sewage plants. Now, some biogas is purified for use as vehicle fuel, replacing about 360,000 litres of petrol annually. Biogas produced from Stockholm's sewage powers two Volvo biogas garbage trucks that collect 12–15 tonnes of waste daily.

The trucks not only produce fewer emissions, but are quieter than previously used vehicles, making them appropriate for use in Stockholm's dense but sensitive urban area Old Town. In the future, Stockholm's waste authority SKAFAB plans to build a facility where food waste collected from restaurants is converted to biogas and fertiliser, and has a goal of being 100% fuel self-sufficient.

1.1.4 Trucks

Commercial trucks come in many shapes and sizes. Most of them are ideal candidates for conversion to natural gas. Trucks that operate in and around the same city are well suited to using compressed natural gas. These vehicles tend to be well-travelled, high fuel consumers operating in downtown, congested urban centres. They have been identified as a source of urban pollution.

Over-the-road *intra*-city trucks may not be as well suited for CNG because of the range they

Fig. 1-8
MAN aerial platform truck in operation in Brussels, Belgium

travel between two urban locations, unless there is a well established fuelling station network set up for this purpose. In Britain and the United States large intra-city trucks are being converted to run on liquefied natural gas (LNG). LNG, stored as a cryogenic fuel has about 60% more energy density than compressed natural gas and, therefore, provides greater range for large trucks operating between urban centres.

Fig. 1-9
Ford Transit operating as delivery vehicle for pharmacies in the greater Koblenz area at CityCargo, Germany

1.1.5 Delivery service

Delivery trucks operating in urban centres are a prime target to be NGVs. Some companies, such as the United Parcel Service (UPS) and the United States Postal Service operate these trucks to deliver mail and packages. They are highly visible in downtown areas and make up a significant part of the polluting vehicle population in metropolitan centres. Also, they have plenty of room for CNG tanks either on-board (usually mounted behind the driver) or within a normally ample frame. Many cities also use CNG delivery vans in urban service, such as senior transport vans in Sutton, United Kingdom.

1.1.6 Fork lifts

Vehicles operating indoors, where air pollution is a serious issue, are a constant cause for concern. Due to worries about indoor air pollution, the fork lift market has been moving relatively rapidly toward natural gas in a

Fig. 1-10
Fork lift in operation in Amstelveen, The Netherlands

number of countries. Forklifts can be purchased directly from certain manufacturers or they can be easily and relatively inexpensively converted. These vehicles can consume an entire tank of fuel in one day and never leave the premises (they are categorised as off-road vehicles). CNG fuel tanks are conveniently located behind the driver or, depending upon the lift-truck design, can be mounted in a specially built rack above the vehicle.

Fuelling forklifts can be much easier than for road vehicles, because they use less fuel and, therefore, require smaller compressors to support their operation. One popular fuelling option has been the use of a small-fleet/home compressor that fills about four litres per hour. Alternatively, they can be fuelled in a couple of minutes from a small CNG storage tank, either indoors or outdoors. Compared to electric forklifts, which require many hours to recharge their bulky batteries, natural gas forklifts are a major improvement.

1.1.7 Taxis and shared cars

Some of the OEMs have designed vehicles specifically for their applications as taxicabs. Compared to their diesel counterparts (which are popular in cities world-wide) natural gas offers major competitive advantages in terms of

Fig. 1-11
Biogas driven taxi, Volvo, in Eslöv, Sweden

fuel price and pollution. In Buenos Aires, diesel taxis were most replaced by NGVs within a relatively short period of time. Today Argentina boasts more than 1,400,000 NGVs, many of which are taxis in Buenos Aires.

The city of Göteborg in Sweden, the hometown of Volvo, has introduced a special line in front of the city's central station, giving clean driven taxis a privileged waiting position. This measure has had a very good impact on the introduction of natural gas driven taxis in Göteborg.

CNG can also be used in car sharing clubs, which has similarly intense energy use patterns. Bremen is using several CNG cars, both as taxis and as car sharing vehicles.

Other major cities in North America, Europe, China, Japan, Egypt and elsewhere are turning to natural gas taxis as a major contributor to improved air quality.

Taxi drivers are concerned about trunk/boot space and refuelling availability. They drive eight and sometimes many more hours per day so time spent finding fuel and at a fuelling station must be minimised. Bi-fuel vehicles help alleviate this problem due to the petrol back-up. In retrofit vehicles, fuelling tanks are often in the boot, and drivers typically are concerned about passengers with luggage not having enough space. Unless a taxicab is specifically assigned to airport duty, however, a vast majority of pickups have little or no luggage, so trunk space should not be a major issue.

For airport taxis there are other options: factory built cabs with the fuelling tanks installed in the chassis, or using small vans where generally there is space enough for a volume of CNG tanks, usually mounted underneath.

1.1.8 Cars

Many of the major automobile manufacturers in Europe, North America and Japan make a variety of natural gas passenger cars. (Many of these same vehicles are also used as police cars and taxis.) Some of these OEM vehicles have passed the most stringent California emissions standards far in advance of their petrol counterparts. The OEMs have gone to great lengths to improve the driving range of these vehicles and a number of them have installed the natural gas storage tanks inside the frame of the vehicle, so trunk/boot space is not compromised.

Fig. 1-12
Multipla Fiat Blupower, 1.6 l, 4 cylinders, 4 valves engine

OEM vehicles are just beginning to enter the market, such as the Fiat Multipla Blupower. Most passenger cars are converted. The newest computer controlled, fuel injected vehicles can be converted using sophisticated conversion systems that are linked to the vehicle's computer, making it difficult to tell if the car is operating on petrol or natural gas.

Local governments, energy companies, police departments and taxi companies use passenger cars as the bulk of their fleet operations. Their concentration in urban centres makes them ideal candidates as NGVs.

Some of the newest factory-built petrol vehicles have made excellent advances in improving their emissions. They are, therefore, beginning to become competitive with bi-fuel NGVs in terms of emissions. That is because the bi-fuel vehicles cannot be optimised to one fuel or the other. As such, some people today are critical of natural gas passenger cars because they are no longer 50–80% cleaner than in the days when carburetted vehicles were in use. If the car is a dedicated NGV, however, there are few if *any* petrol or diesel cars that can compare from an emissions standpoint. Some of these natural gas vehicles are lower polluting than an electric car if the electricity is generated using coal or oil!

1.2 Leasing options

Some dealers of OEM NGVs will be able to lease an NGV as easily as they can a petrol or diesel version. As long as the vehicle has been certified for operation in that country, there should be no special problems leasing a new NGV.

Some short-term leasing companies now offer NGVs in limited locations. Most companies leasing a large number of commercial vehicles to corporate customers are not yet attuned to providing NGVs. However, since natural gas conversion systems can be removed from a vehicle and returned to ordinary petrol service (and sometimes the gas systems reinstalled on another vehicle), there should not be a major problem for a company to lease NGVs if they are requested to do so by the customer! As the fuelling infrastructure is expanded, leasing companies undoubtedly will increasingly offer an NGV option.

1.3 Second-hand market

Finding a buyer for a used NGV can be a problem at the moment, without an established sophisticated fuelling station network. A typical fleet vehicle has a life span of 3–5 years and is taken out of service (usually because of high mileage) and scrapped or resold. Corporate users of these vehicles typically have standard intervals for service and maintenance. As such, they can be resold as a decent used vehicle.

There are some creative solutions that can be pursued.

- Local governments can be candidates to purchase used NGVs from, say, energy companies. The higher first cost of conversion to natural gas can be absorbed by the energy company so that the local government has access to a decent vehicle, running on a cheaper fuel, and whose first cost is competitive with a used petrol vehicle.
- Companies with NGV passenger/van fleets can sell their cars to their employees. When employees come to work they can use the corporate fuelling facilities, either fast fill or, during their working hours, at a slow fill station.
- The NGV associations can become a source of advertising for used NGVs. Their websites are beginning to expand, and many people are visiting them for increasingly more information (Please refer to section 9).

2. Fuelling of natural gas vehicles

2.1 Introduction

The lack of filling stations is one of the crucial points for the wider market implementation of natural gas vehicles. However, during recent years the number of filling stations has grown in all European countries, e.g., Italy 500, Germany 540. The location of the filling stations can be obtained from the national gas associations and are often published on the homepages of these organisations (please refer to section 9).

A CNG filling station consists of the incoming natural gas pipeline providing a pressure of 1–30 bar. The main parts of the filling station are the compressor, gas dryer, a high pressure system (200–250 bar) with a storage system (fast fill option), electric instruments for measuring and control, gas pump and a cover (encasement, building). Two types of fuelling systems are available on the market: fast fill and slow fill systems.

Slow fill or fast fill?

Slow fill is a possibility if the fleet is used during the day with parking at the depot at night (or vice versa). During standstill the vehicles are filled directly by the compressor. Fast fill is used if filling has to be completed within a few minutes, e.g., for supply to external customers and large natural gas demand justifies the higher investment costs.

How to find the right system?

The capacity of the filling station has to be designed according to the CNG demand per time unit. Primarily the following parameters have to be taken into consideration:

Fleet parameters

- Number of vehicles
- Mileage per vehicle
- Consumption per kilometre
- Volume of fuel storage on-board
- Number of refills per time unit (fast fill)
- Duration of the filling period (slow fill).

Location parameters

- Locality, driveway
- Vehicle characteristics (weight, steering radius)

Fig. 2-1
Fast-filling at Ruhrgas in Dorsten
Ruhrgas AG

Fig. 2-2
Tank opening at the vehicle
Ruhrgas AG

Fig. 2-3
High-pressure hose with plug coupling
Ruhrgas AG

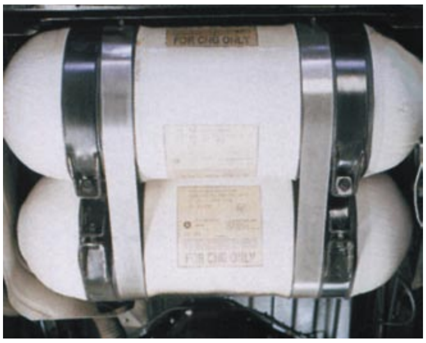


Fig. 2-4
Tanks are installed under the rear
Ruhrgas AG

- Gas connection (location, design, intake over-pressure)
- Electric connection (location, design).

Pre-feasibility
- Module sizes
- Capacity of the filling station
- Necessary storage volume
- Number of dispensers
- Design of other facilities
- Elaboration of filling cycles
- Design of modular extendable system
- Investigation of alternatives
- Economic analysis
- Discussion of safety of supply

Estimation of investment volume
- Rough framework of quantities
- Determination of standard purchase prices for all components, work and engineering
- Evaluation of different alternatives.

2.1.1 Fast filling

Fast filling with CNG requires no more time than filling with conventional fuels such as petrol or diesel. This is usually needed when vehicles must be refuelled in a time period similar to that of gasoline, say 3–7 minutes for automobiles and light-duty trucks.

At a fast fill fuelling station, natural gas is compressed by the compressor and stored in the high pressure storage system, e.g., in gas storage cylinder "cascades". When vehicles are being refuelled and the pressure of the fuel supply in the storage system begins to drop, the compressor is automatically activated, causing it to replenish the supply of natural gas in the storage cylinders. Other systems are working with a hydraulic piston system which keeps the pressure in the storage system always at the same level. A dispenser then delivers and meters the natural gas into the fuel storage cylinder(s) onboard the vehicle. In detail the following equipment is needed:

Compressor

In a fast fill application high stationary storage pressure and capacity present good working conditions. Compressors serving fast fill stations are capable of providing at least 250 bar. Compressors are available with flow capacities from 0.8 litre/sec to hundreds of litres/sec. Compressor controls guarantee safe operation. Critical pressures and temperatures are monitored by shutdown devices.

Visual indicators are usually provided to indicate the operating or shutdown condition.

Controls

The controls required depend on the type of station specified. Basic controls determine the flow of gas to and from the compressor, the gas recovery system and to the dispenser. Most compressors have their own control system for start/stop, monitoring and safe operation. When high pressure cascade storage is installed, a higher level of controls must be installed to determine to and from which tank or bank of cylinders the gas will flow.

A pneumatically or electrically operating valve system, so-called priority system, directs the natural gas coming from the compressor into either high, mid or low pressure storage banks. The controls switch from bank to bank until all have been filled to maximum storage pressure. The compressor is then switched off automatically.

The sequence system of valves controls the flow from the storage system to the vehicle. Only a portion of each bank's capacity can be used due to pressure equalisation between the vehicle and the storage system. As the pressure difference between the vehicle and storage system is reduced during the refuelling process, the flow rate decreases. In order to achieve maximum filling efficiency, the sequence valve system switches to the next bank. The usable portion of the storage varies from system to system with manufacturers in the range of 25% to 60%. An average can be estimated to be 30%. As storage pressure increases these percentages will change. This is important as it affects the total amount of storage needed and may also affect the compressor size.

Fig. 2-5
Side view: High-pressure tanks under the vehicle
Ruhrgas AG

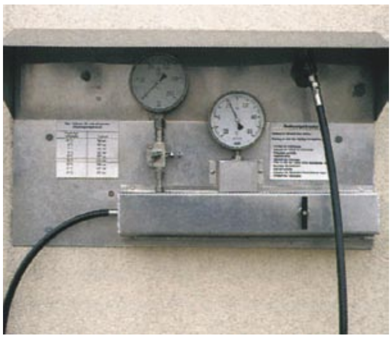


Fig. 2-6
Metering pressure and fuelling quantity
Ruhrgas AG

Fig. 2-7
Slow-filling station in Poitiers, France

Storage system

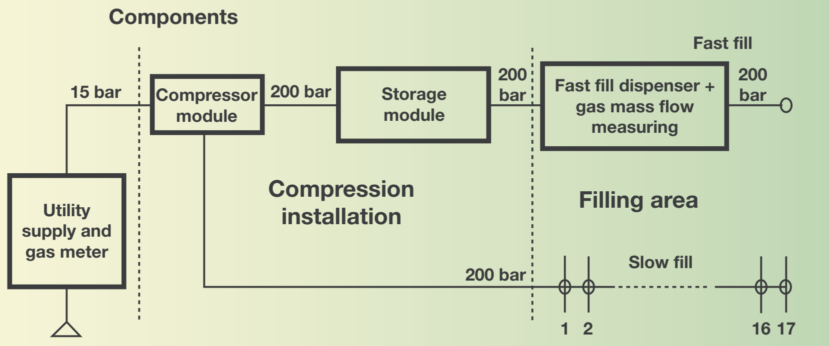
For the storage system a variety of synonyms exists. They are often referred to as bottles, receivers, tanks, banks, cascades, pressure vessels and cylinders The most common cascade systems divide the storage into high, mid and low tanks or banks. Whereas each bank is filled to the same working pressure, the terms high, mid, and low refer to the level the pressure will be reduced to once fuelling begins. Some systems use only two different pressure levels.

As an example, assume a system has all banks in a three bank storage system which are filled to 300 bar. Once vehicle filling begins, the stored natural gas will flow into the vehicle until the pressure in the low tank is reduced to 70 bar, then the controls will switch to the mid tank where the flow will continue until the pressure between the vehicle and tank equalises at 140 bar. Finally, the high bank will top off the vehicle storage at 250 bar. The controls will initiate refilling the storage as soon as the pressure in any bank drops below the compressor cut-in pressure setting and stop when all storage is at maximum pressure again.

Dispenser system / Metering

All stations must have a dispenser in order to fill vehicles. This may be as simple as a fill post with hose and nozzle or it may consist of a programmable double hose metering dispenser with display and card lock system similar to a gasoline pump. A break away device is usually required to stop the gas flow in drive away situations.

The two types of metering devices currently used are mass flow and sonic nozzle. Both are built into dispensers in order to account for, bill, or calculate natural gas usage. Specifications



Descripción general

1 Módulo compresor con dos compresores:

Presión de entrada nominal:	15 bar indicador
Presión de entrada mínima:	10 bar indicador
Presión de salida nominal:	200 bar indicador
Tasa de flujo:	2x159 m^3 (n)/h
Tipo de compresor:	Gemelo hidráulico
Número de etapas de compresión:	2
Potencia nominal del motor:	70 kW
Factor de potencia (cos phi):	>0,9
Paquete condensador:	para mejorar factor de potencia
Potencia considerada:	80 kVA

1 Módulo de alacenamiento, contiene:

2 unidades de almacenado, cada una con 2 x 12 cilindros con capacidad de 50 litros de agua
= 2.400 litros de capacidad de agua, correspondientes a 540 m^3 (n) de gas natural disponible

1 Dispensador de llenado rápido equipado con:

Scout de combustible (lector de tarjeta y control de admisión)
1 manguera de distribución con un conector de llenado de perfil VGN
1 unidad de medición de flujo de masa
Gas residual de la manguera de distribución evacuado vía abertura de recuperación

17 Dispensadores de llenado lento:

Cada dispensador equipado con 2 mangueras de distribución con un conector de llenado con perfil VGN

Fig. 2-8
Combined slow & fast fill NGV filling station for filling 34 refuse collection vehicles
NGVeurope, 1999

should be read carefully in order to determine if a metering device is required.

Temperature compensation at the dispenser is also commonly specified. This can be electronically calculated or controlled through the use of pressure sensing valves and reference cylinders. It is important because over-pressurising vehicle storage can occur. Conversely, underfilling is a nuisance that can be minimised through the use of temperature compensation.

Another aspect of fast filling is the slightly reduced fuel storage capacity on the vehicle in comparison with a slow filled tank of the same type and the same pressure. The reason is, that as the gas rapidly builds up and compresses the gas that is already there the temperature in the tank will rise, which in turn lowers the density of the gas. With the slow-fill approach this effect will not be encountered because of the significantly lower temperature rise during refilling.

2.1.2 Slow filling

The fuelling of vehicles with slow fill stations occurs directly from the compressor through special slow fill dispensers. This eliminates the need for a costly high pressure storage system but lengthens the fuelling process to several hours for every vehicle. A slow fill compressor only needs to develop a pressure slightly higher than the vehicle storage pressure. Slow fill is usually recommended for fleets where vehicles return to a central location for 6 to 8 hours or private cars which can be refilled overnight at home.

Components of a slow-fill station are:

- Access to natural gas piping system
- Compressor
- Slow fill dispenser.

2.1.3 Combination of slow and fast filling options

Also, a combination of both fast fill and slow fill is possible and can be an interesting solution for big fleet operation when just a part of the fleet needs fast fill thus reducing the requested onsite storage capacity and saving investment costs [NG Vehicle Coalition, 1995].

Combination of slow and fast filling options is also advisable if it is impossible at the beginning of an NGV project to predict how fast the demand will grow. A filling station can be expanded any time. Building a filling station that can be expanded as an NGV fleet grows minimises the investment risk. Combination of fast and slow fill can also be used to serve different user groups, e.g., external customers are served in fast fill operation and the company vehicles can be filled in slow fill operation during the night.

2.2 Economics

Depending upon the design of the service station, its fuel storage requirements and the vehicles to be refuelled, investment costs for the filling stations range from 3,500€ to 10,000€ for slow fill systems that can serve only a few vehicles to several hundred thousand Euro for large stations capable of fast filling and fuelling over a hundred vehicles. For normal fleet vehicles, however, as a general rule you can expect to spend 1,000–2,000€ per vehicle to install a fuelling station. [IANGV homepage]

The revenue of the filling station has to cover at least the investment and operation costs as well as giving a market interest rate for the capital employed. The revenue depends on fuel sales volume and fuel price. To reach payback point the price at the "petrol pump" has to be:

Costs for natural gas purchase (See section 4.1)
+ Mineral oil tax (Refer to section 4.1)
+ Cost of capital
+ Energy costs
+ Operation costs

Minimum price at petrol pump

2.2.1 Investment / capital costs

The costs for the filling station include the costs for the compressor, the cascades for intermediate storage, the dispensers and construction costs. To the best extent possible, the compressor should be selected to reach an optimum utilisation of up to fifteen hours per day. The intermediate storage should have the capacity to refill approximately 50% of all vehicles per day. In the following, all costs represent average values. The investment costs are converted to yearly capital costs using a capital recovery factor taking into consideration an operating life of 10 years for technical equipment and 40 years for buildings, with an interest rate of 7%.

Refills per day (cars)*	Suction volume flow (m^3/h)	Suction pressure (bar)	Investment (Euro)	Compressor operation time**
4	3	1.013	5,000	20.0
10	10	1.013	50,000	15.0
20	20	1.013	60,000	15.0
40	45	1.013	80,000	13.3
100	114	1.013	185,000	13.1
150	160	1.013	200,000	14.1
200	240	1.013	210,000	12.5
150	170	16	165,000	13.2
200	350	16	200,000	8.6

Fig. 2-9
Average investment for compressor station

* For refilling of one car (fuel storage of 80 litres) 15 cubic metres natural gas are necessary. A van counts for two cars. A bus or a truck counts for 10–15 cars.
**For maximum number of refills per day [h]

Storage volume	Costs [Euro]	Capacity
640 l (8x80 l)	8,000	4 cars
800 l (10x80 l)	9,000	10 cars
960 l (12x80 l)	10,000	20 cars
2.000 l (25x80 l)	15,000	40 cars
2 x 3,200 l (40x80 l)	2 x 70,000	100 cars
8,400 l (4 x 2,100 l)	120,000	150 cars
+ storage control	5,000	
+ emergency lock	5,000	

Fig. 2-10
Investment costs for intermediate storage bench

The investment for the compressor includes costs for natural gas dryer, noise and weather protection, natural gas control system, spare parts, freight and packaging, montage, and putting into operation (Please refer to Figure 2-9).

The approximate investment costs for the intermediate storage cascades are given in Figure 2-10. For the refilling of 200 cars/day a storage of 960 litres is sufficient, because the suction volume flow of the compressor is large enough to fill vehicles also directly in only a few minutes.

The investment costs for the dispenser with one hose—sufficient for 40 vehicles per day—are 25,000€ or with two hoses 40,000€, including data collection system and protocol printer.

The construction costs including collision protection, roofing of the dispenser and connection to the electrical and gas network can be estimated as follows:

- 25,000€ (4 cars per day)
- 50,000€ (10 cars per day)
- 100,000€ (from 20 cars per day)

The operation costs are the maintenance costs for the filling stations which can be estimated to be 5% of the investment costs of the compressor.

The energy costs are mainly caused by the operation of the electrical engine of the compressor. These costs can be obtained from the performance data given by the manufacturer. Average costs are given in Figure 2-11.

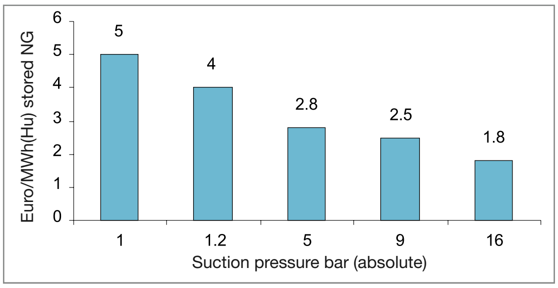


Fig. 2-11
Specific energy costs for NG filling station

Germany promotes CNG-projects

The German Federal Environmental Ministry has since 1993 financed four CNG-projects in Germany, in cooperation with the German Federal Environmental Agency. The additional cost of approximately 3,700 CNG vehicles, and the cost of CNG-filling stations, were covered totally or in part. The German government decided in 2002 to reduce the fuel tax on CNG-fuel up to 2020 corresponding approximately to the minimum fuel tax as required in the member states of the European Union.

Fig. 2-12
*Total costs for the filling station operator (*incl. natural gas supply costs of approximately 15€/MWh_{Ho})*

Refills per day (cars)	Suction volume flow [m^3/h]	Storage volume [l]	NG consumption, 100% utilisation [MWh_{Ho}/a]	Total costs for 100/50% utilisation	Energy costs [€/MWh_{Ho}]	Necessary fuel price for 100/50% utilisation
4	3	640	153	6.1/12.2	5.0	8.1/14.2
10	10	800	382	5.3/10.5	5.0	7.3/12.6
20	20	960	764	3.7/7.4	5.0	5.7/9.4
40	45	2,000	1,530	2.1/4.3	5.0	4.2/6.3
100	114	6,400	3,820	1.6/3.2	5.0	3.6/5.2
150	160	8,400	5,730	1.2/2.5	5.0	3.3/4.5
200	240	960	7,640	0.8/1.5	5.0	2.8/3.6
150	170	8,400	5,730	1.1/2.2	2.5	2.9/4.0
200	350	960	7,640	0.7/1.3	2.5	2.5/3.1

Roughly, for the economic analysis energy costs of 5 respective 2.5€/MWh_{Ho} for suction pressure of 1 or 16 bar can be used.

With the increasing size of the compressor and the assumption of the optimum utilisation of the filling station the share of the debt service and operation costs decrease over proportionally. The costs are between 6–3€/MWh_{Ho}, with increasing size of the filling station this costs share can be decreased down to 0.7€/MWh_{Ho}. Plus NG supply and energy costs fuel costs at the station amount to between 8.1 and 2.5€/MWh_{Ho}.

At smaller filling stations the investment costs have the crucial influence on the fuel price, that means a reduction of the investment costs results in lower fuel prices. For large filling stations the situation is the exact opposite. Gas supply and energy costs have a decisive influence on the fuel price. The energy costs could be decreased by connecting the filling station to a high pressure network. For example, the increase of the suction pressure to 16 bar reduces the fuel price from 3.3 to 2.9€/MWh_{Ho} for a filling station with a capacity for 150 cars/day.

2.3 Financing of infrastructure

Investment in the infrastructure most often is borne by the natural gas industry. The integration in the filling station network of the traditional oil industry is essential to reach smaller fleets and private customers.

Fleet operators interested in natural gas vehicles should contact their local gas supplier to receive information about the location of filling stations. Depending on the gas demand of the fleet, the gas supplier could be interested in investing in the filling station. Natural gas filling stations have an advantage in that they have a demand for natural gas which does not depend on the season, such as the heat NG market.

Typically the gas company and the fleet operator agree on a minimum amount of natural gas supply and a fixed price for the natural gas which may be scaled according to the amount of natural gas sales.

Within the ZEUS project, in almost all cases municipalities using CNG have covered at least some of the cost for infrastructure provision, service, and maintenance. This is especially true when the local energy or fuel provider is a municipally-owned company. However, in many cases fuel providers have been willing to cover the cost of infrastructure provision if the municipality ensures a volume purchase.

- ***CNG refuelling in Athens***: The municipality bought the compressor, but the gas supplier DEPA provided a standard cabinet, regulator, and meter. DEPA also supervised all construction work for the connection of the compressor to the pipe network.
- ***CNG in Bremen***: Two public refuelling facilities have been implemented by Shell and Esso, a third private facility was financed by the gas provider Enordia and is used for its own fleet.
- ***CNG fast fill in Merton and Sutton***: Stations built by British Gas on the basis of ten-year fuelling agreements.
- ***Biogas refuelling in Stockholm***: Stockholm produced four refuelling sites for biogas in co-operation with the fuel providers OK, Q8,

Statoil, and Shell. The fuel is locally produced at the local sewage facility.

2.4 Land use planning for refuelling stations

Before any infrastructure is ordered, review land use regulation for any possible restrictions that may affect infrastructure siting. In most cases, these regulations have been written with petrol or diesel infrastructure in mind, and obtaining variances or permits can take considerable time and effort. Safety is of particular concern in planning infrastructure, especially when tanks or other equipment are housed underground or have special ventilation requirements.

Land use planning can also be a tool for the optimal siting of infrastructure. For example, Geographic Information System (GIS) analysis can help determine which available site best serves a certain fleet, or calculate the municipal "coverage" of several vehicles.

Interest in CNG in developing countries

Many developing countries are showing interest in expanding the use of CNG, both as a 'clean air' and 'fuel security' issue, especially countries with gas reserves. With ultra-low sulphur diesel offering a similar emissions performance to CNG, future interest in CNG may be greatest where domestic supplies can reduce costly petroeum imports.

- In December 2002 Delhi had 7,400 CNG buses: 45,000 CNG three-wheelers, 10,350 private cars, 4,000 minibuses, and 15,000 taxis.
- Beijing, which will host the 2008 Olympics, had 1,630 CNG buses in early 2002. In addition, the city has converted 36,000 vehicles, most of them taxis, into CNG vehicles (Reuters Business Briefings, 13-Apr-02).
- Dhaka in January 2003 implemented a ban on two-stroke three-wheelers. By early 2003 the government had given permission to 5,000 CNG auto-rickshaws to operate, and was encouraging expanded use of CNG.
- A German government co-financed public-private partnership "Bus Quality Improvement Project" was launched in Nov. 2002 in Jakarta, involving cooperation between the City of Jakarta, DaimlerChrysler and the operators Damri (public) and Bianglala (private). Current Euro 0 buses will be compared with Euro 2 diesel buses and CNG buses in a one-year pilot project.

3. Emissions of natural gas vehicles

NGVs are known for their overall contribution to cleaner air and lower emissions than either petrol or diesel vehicles.

Emissions compared to petrol vehicles

Natural gas has low carbon monoxide (CO) emissions, emits virtually no particulate matter and has reduced volatile organic compounds (VOC). Per unit of energy, natural gas contains less carbon than any other fossil fuel, leading to lower carbon dioxide (CO_2) emissions per vehicle kilometres travelled. Cold-start emissions from NGVs are also low, since cold-start enrichment is not required, and this reduces both non-methane hydrocarbons (NMHC) and CO emissions. Specific emission reduction levels for NGVs compared to petrol are:

- CO, up to 60–80%
- Non-methane organic gas (NMOG), up to 87%
- NO_x, up to 50–80%
- CO_2, by about 20%
- Ozone-producing reactivity, up to 80–90%

(These numbers will vary depending upon the comparative vehicles used.)

Evaporative & refuelling emissions

Another emission benefit is achieved when fuelling NGVs. Petrol vehicles have evaporative emissions during both fuelling and use. These emissions account for approximately 50% of a vehicle's total hydrocarbon emissions. Natural gas, because the vehicle system is a closed, pressurised system, has no evaporative emissions.

Emissions compared to diesel vehicles

There is a wide range of diesel engines of different sizes, used for various applications. When running on diesel fuel, these engines function on the 'heat of compression'. The diesel fuel is pressurised in the cylinder head and then 'auto-ignites' when put under pressure. One hundred percent natural gas used in a diesel engine functions only if a spark plug is introduced, since natural gas ignites at more than double the temperature of diesel. Thus, the diesel engine retains the heavy duty long life characteristics of its original design but is

Pakistan expands CNG use in the transport sector

Pakistan is a major user of CNG, which has recently been rapidly expanded in the transport sector. As in other developing countries, the primary motivating factors are the lower emissions of CNG and issues of fuel security.

As of August 2002, more than 280,000 vehicles had been converted to CNG and 333 CNG stations were operational while another 300 were under construction in different parts of the country (Hydrocarbon Devt. Institute of Pakistan, http://www.hdip.com.pk/hydrocarFSUB.htm). Figures for 1991 indicated that the then 200,000 vehicles converted to CNG consumed approximately 30 million cubic feet of gas daily, replacing 292,000 tonnes of petrol per annum and accruing foreign exchange savings of $60 million (*The News*, 30-Jul-01; http://www.jang.co.pk).

Supportive policy framework

Rapidly expanding use of CNG in Pakistan is largely a result of the strong government commitment to promoting CNG, including a policy which links the price of CNG to the price of gasoline.

The CNG city: Delhi*

* Anumita Roychowdhury, Coordinator, Right to Clean Air Campaign, Centre for Science and Environment, New Delhi, India

The CNG mandate in Delhi

On July 28, 1998 the Supreme Court of India ruled, in the ongoing public interest litigation on air pollution in Delhi, that the public transport bus fleet of Delhi should be increased to 10,000 by April 1, 2001, and that the entire bus fleet along with three wheelers and taxis should be converted to CNG.

The objective was to leapfrog Delhi to better emissions levels than the poor Euro 0 standards in force then, with a remote possibility of Euro 2 emissions standards only by 2005. Natural gas was already available in Delhi for industrial and household use. The mandate was to make natural gas available for transport to address the alarmingly high levels of particulate emissions in one of the most polluted cities of the world.

The CNG order was not easy to implement in Delhi. Resistance from the entrenched diesel business, lack of policy support from the government, and doubts of the viability of the program held up progress. Despite such resistance, the Supreme Court finally ruled on April 5, 2002 that the orders and directions of the Court on CNG cannot be altered by any administrative decision of the government, and dismissed all objections to the program. The city witnessed a large increase of CNG vehicles following the Court order.

Despite difficulties, the expansion of the CNG program has been impressive. There are more than 75,000 CNG vehicles in the city: 7,400 buses, 4,000 minibuses, 45,000 three-wheelers, 15,000 taxis and 10,350 cars. On December 1, 2002, Delhi's entire bus fleet became diesel-free, perhaps representing the largest city CNG bus fleet in the world. An extensive network of CNG refuelling stations is in place. Of the total number of 103 CNG refuelling stations, 60 (including 46 mother stations) are online stations, 30 daughter booster stations, and 13 daughter stations are online. CNG sales have increased dramatically from 0.99 lakh kg per day in March 2001 to 6.5 lakh kg per day in January 2003.

Key challenges

The CNG program implemented as an urgent strategy to cut vehicular particulate emissions uncovered the challenges of deploying a new technology on a large scale. Delhi's experiences with CNG have thrown up many lessons for other Asian and developing countries contemplating such technology.

- ***Preparedness to design appropriate regulations for the new program***: Not surprisingly due to the lack of experience, weak emissions and safety regulations, inadequate safety and emissions inspection systems, poorly planned refuelling infrastructure, and *ad hoc* procedures for converting old buses to CNG afflicted the new program.
- ***Institutional capacity to address new operational problems***: Operational difficulties are to be expected in a program involving new technology introduced on a large sale. But this requires immediate corrective action through constant monitoring and evaluation of the technology, refueling infrastructure and enforcement of safety and emissions rules. The 12 CNG fire incidents on buses reported during 2001–2002 exposed the weaknesses in the regulatory capacity.
- ***Independent technical evaluation and monitoring for corrective action***: In the face of weak institutional responses, the onus shifted to civil society groups and the judiciary. New Delhi-based Centre for Science and Environment (CSE) organised two independent technical evaluations of the CNG program in May 2001 and June 2002 to provide policy direction.** The key recommendations of these evaluations became the basis of the reports on safety and emissions standards for CNG buses submitted by the Environment Pollution (Prevention and Control) Authority (EPCA), the statutory committee that advises the Supreme Court of India in pollution control matters in

** The two expert reports were:
- Frank Dursbeck, Christopher Weaver, Lennart Erlandsson, 2001, *Status of Implementation of CNG as a Fuel for Urban Buses in Delhi*, Centre for Science and Environment, New Delhi, May 23.
- Lennart Erlandsson and Christopher Weaver, 2002, *Safety of CNG Buses in Delhi*, Centre for Science and Environment, New Delhi, August 9.

Fig. 3-1
A row of CNG buses in Delhi.
Centre for Science and Environment

Delhi. These reports led to the revision and notification of rules for emissions and safety for CNG vehicles in November 2001. A new safety inspection system was set up in August 2002.

The technical evaluations confirmed that several improvements were needed, including a better institutional framework for coordinated action, regular inspections to ensure compliance with safety regulations and training for capacity building. In order to ensure that current and future safety issues are diagnosed, solved and implemented, the Supreme Court order of July 29, 2002 made compliance with the revised safety rules and special inspection systems for CNG buses mandatory with immediate effect in Delhi.

Institutional framework

- A separate safety council has been instituted by the Delhi government to deal with CNG related safety issues and carry out "root-cause" evaluations of CNG-related safety problems, identify solutions, and ensure implementation. This is also expected to improve the interface between the type approval agency and the inspection centre in the city for feedback and constant monitoring.
- Independent third party inspection of CNG buses different from the existing annual fitness inspection system for all vehicles has started. Buses identified with flawed features are sent back for remedial action. Only a rigorous pre-registration inspection of the engine and high-pressure fuel storage system can detect lapses. Some of these include: stress loops at the gas piping from the gas cylinder missing; diameter size of the pipes connected to the gas cylinders not according to specifications; insufficient clamping of gas pipes on several locations; not enough distance between gas cylinder and exhaust mufflers and without heat shield; dust protection cap missing at the gas filler inlet; and insufficient flexibility in the high-pressure gas piping.
- This makes government authorisation of CNG conversion workshops essential. But technical and legal requirements for authorisation have not yet been defined. Irrespective of the type approval certification, inconsistencies with approved specifications are common. Experts therefore recommended that in order to prevent defects in safety features, the approval certificate should be recalled in case of non-compliance.
- Periodic training of inspectors on instruments and test procedures has recently been initiated. Upgrading of instrumentation and testing facilities is another issue that was revealed during the expert evaluation.

Fig. 3-2
CNG piping in a converted bus, without stress relief loops.
Centre for Science and Environment (Erlandsson & Weaver 2002)

Fig. 3-3
CNG piping in a converted bus, without stress relief loops and inadequate clamping of gas pipes.
Centre for Science and Environment (Erlandsson & Weaver 2002)

Issues in program content

The technical evaluation in May 2001 showed that emissions norms were weak, particularly those for converted buses. In accordance with the original ruling, after conversion the buses were only required to meet the corresponding diesel emissions standards in force during the year of manufacture. This meant that diesel buses of pre-Euro 1 vintage after conversion to CNG would need to meet only Euro 0 norms. Such weak norms could only encourage very basic, poorly developed retrofit and conversion systems and lead to very unstable on-road emissions. Similarly, the limit value of 3% CO for in-use idle test was found to be too lax, as a CNG bus with a properly functioning air-fuel ratio control system and catalytic converter is

Fig. 3-4

Night time refuelling of CNG three-wheelers and taxis at dispensing stations in Delhi.

Centre for Science and Environment

expected not to emit more than 1% CO. Yet the study found that 18% of CNG buses tested for idling CO at the inspection centre exceeded even the 3% limit value.

Some legal amendments followed these findings:

- Euro 2 emissions standards were made mandatory for new CNG buses and Euro 1 mandatory for converted buses
- Safety norms were modified to adopt the safety code of practice for use of CNG in internal combustion engines, AIS–028, in addition to the AIS 024 safety procedures for type approval of CNG vehicles
- Pre-registration inspection for all CNG buses was made mandatory
- A new type approval for each separate diesel engine make and model to be retrofitted was also made mandatory.

Accelerated introduction of a large number of CNG vehicles in the city also required that the testing facilities and capabilities for type approval were expanded and improved to reduce the duration of the whole type approval procedure to a reasonable, internationally acceptable timeframe.

The experience showed that there exists an additional risk of regulations becoming too convoluted for customers to understand. This happened for instance over the provision that new type approval for each separate diesel engine make and model would have to be obtained for conversion of in-use diesel buses to CNG. This led to the confusion whether all variants of each model would need to go through the whole test process. Certification agencies were therefore advised to issue guidelines on how to interpret the type approval regulations and related documents on test procedures, especially for conversion.

Role of the industry in voluntary remedial action

Delhi's experience was an unusual mix of evolving regulations and a voluntary action by the industry to address safety-related engineering issues to make incremental modifications. Bus fire incidents exposed many engineering flaws related to safety that surfaced only during on-road operations. Some of these include

Fig. 3-5

CNG bus refuelling station, Delhi.

Centre for Science and Environment

insufficient flexibility in the high-pressure gas piping, which resulted in some high-pressure gas pipes being pulled out of their fittings while the bus was in motion; high failure rate of “burst disks” (pressure relief devices or PRDs), usually while the vehicle was being refueled; damage caused to the high pressure gas piping as a result of accidents; among other engineering safety issues.

Bus manufacturers had begun to address most of these problems and were on their way to finding solutions (change piping, replace burst discs with a fusible thermal pressure relief device and make other design changes for proper venting of gas in case of leakage, etc). But constant monitoring is still needed as these studies show that there is room for improvement in areas such as material of the high-pressure piping, fixing of pipes to the chassis, tightening of the couplings, venting of the pressure relief valve, and improving the ignition system.

Issues in dispensing of CNG

CNG is a court mandated market in Delhi and the entire program had to be implemented within a short timeframe. But refueling facilities to cope with the expected increase in demand were not planned. This led to transitional problems of delayed filling and long queues. Timely intervention from the Supreme Court backed by technical evaluation led to many corrective changes. These included:

- extension of pipeline to increase the number of online stations and a lower number of daughter stations;
- odourisation of gas for safety reasons;
- application of advanced nozzles to lower gas filling time,
- other measures.

Conclusion

Several problems remain to be resolved, but fuel switching has been an immediate and an intermediate abatement strategy in Delhi, where entrenched gasoline and diesel technologies would have taken a long time to advance. Delhi demonstrates how other cities can face up to the challenge of introducing alternative fuels and technologies to meet better air quality targets.

CNG in Surabaya, Indonesia

Background

A GTZ feasbility study conducted in 1999 retro-fitted three gasoline microbuses with CNG.

Surabaya has around 5,000 microbuses, and is one of several large Indonesian cities with an existing CNG distribution infrastructure. Indonesia has substantial reserves of natural gas. The city's largest taxi operator has been running CNG taxis since 1996, and currently operates around 800 CNG taxis. Nearly 3000 gasoline microbuses operate routes passing within 200 metres of existing gas pipelines, and of these around 275 vehicles are less than 5 years old (the limit on what is considered feasible for retrofits).

Findings of the study

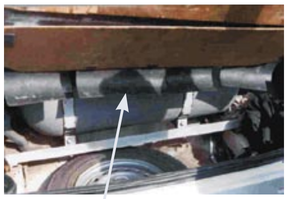
The study, available in Indonesian at http://www.sutp.org, found that use of CNG for microbuses in Surabaya is technically, economically, environmentally and socially feasible for microbuses which have routes passing close to a gas filling station. A microbus consuming an average 23 gasoline-equivalent litres of CNG per day—based on fuel prices in 1999—would achieve break even point (BEP) on repaying the cost of the CNG retrofit in less than 2 years. A microbus consuming only 13 gasoline-equivalent litres per day would achieve BEP in around 3 years. Since the study was completed the economic feasibility of CNG has further increased, as gasoline prices have risen around 75% since Oct. 2000 while the price of CNG has increased only slightly over the same period.

Working Groups and awareness-raising

One successful feature of the approach in Surabaya was a "Working Group" mechanism which involved local stakeholders in developing action plans. Key topics of CNG policy, infrastructure and financing all had separate Working Groups. Stakeholders included microbus workshops, the state gas company, bankers, the state fuel company, officials from a range of related agencies, owners/drivers assocations, and others. Targetted awareness-raising of the feasibility of CNG was also conducted as part of a wider campaign.

Future directions

Despite strong local support, there has so far been no expansion in the use of CNG. The main obstacle to investment in conversion kits and refuelling infrastructure appears to be the national government's lack of strong policy support (including a pricing policy) for CNG. The Surabaya City Government will however fund retrofits of selected official vehicles in 2003, aiming to provide an example for the city's people and demonstrate a concern achieving cleaner air.



CNG tank

A trial of 3 microbuses in Surabaya demonstrated feasibility of CNG, though significant obstacles remain, including presence of only a handful of refuelling stations, and a perceived lack of central government commitment to CNG.

transformed into an Otto cycle engine (like gasoline). The best emissions results typically come from dedicated natural gas engines although there have been some breakthroughs in dual-fuel technology.

Emissions reductions from using natural gas in heavy duty engines typically are in the ranges:

- CO, 70–90%
- Non-methane organic gases, 40–60%
- NO_x, 80–90%
- Particulate Matter (PM_{10}), 90–95% (Note: Much of the particulates emitted tend to be from engine lubricating oil encroaching inside the piston head and is not a direct result of the natural gas fuel.) [Energy Information Administration, homepage]

NGVs global warming contribution

Many people are concerned about the global warming potential (GWP) of NGVs because these vehicles emit amounts of unburned methane (a non-ozone forming hydrocarbon) that typically is in excess of the existing total hydrocarbon (THC) standard for petrol vehicles. Methane is, in fact, a global warming gas, however, compared to petrol vehicles, considering CO_2 and methane, the GWP of an NGV is about 20% less than a petrol vehicle and about the same or slightly less than a diesel engine. Natural sources of methane emissions—livestock, rice fields, termites, etc.—produce far more methane than will be created by hundreds of thousands of NGVs on the road.

For example, the German Ministry of Environment estimates that if 10% of the diesel fuel was replaced by natural gas, the contribution of the total methane emissions in Germany would be between 0.0004% and 0.0017%, depending upon the type of engines being used.

Noise emission

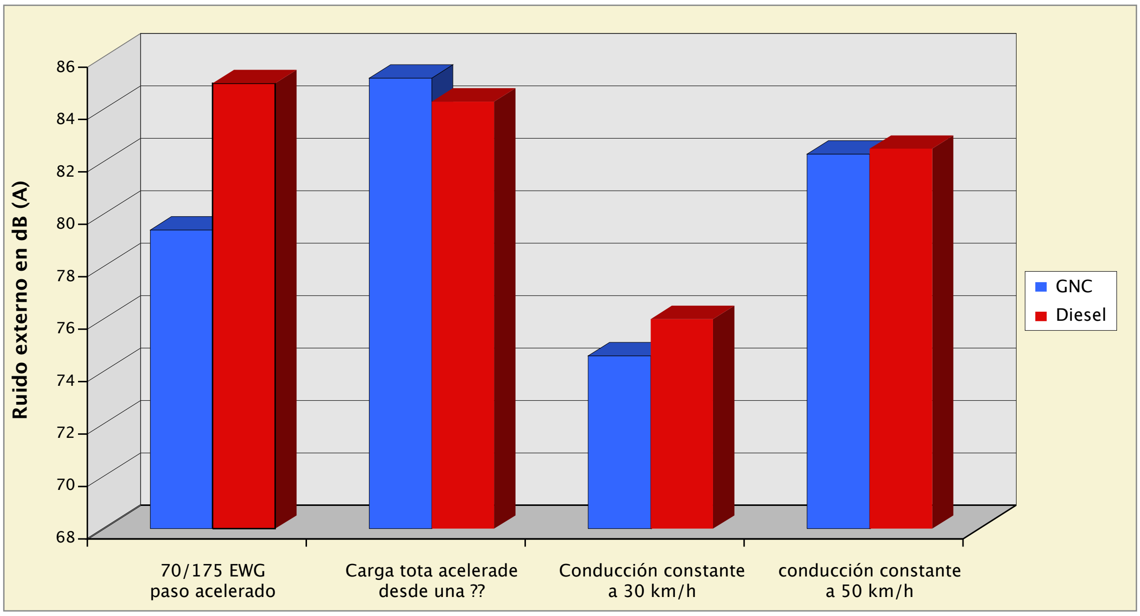
Noise emission from vehicles poses a serious pollution problem for human beings. Natural gas powered vehicles operate quieter than, in particular, diesel vehicles. This is important especially when the vehicle is operated in public transport. The Natural Gas Bus Project Berlin recorded the noise of different bus types running on both diesel and natural gas*.

Figure 3-6 shows the results of the external noise recordings. The values measured at a constant speed of 30 km/h and 50 km/h as well as from simulated acceleration away from a bus stop differed between diesel and CNG by approximately 1 dB(A). The accelerated overtaking showed a noticeable difference in favour of the natural gas vehicle by 3.3 dB(A). An increase of 3 dB is equal to a doubling of the noise effect. [The Natural Gas Bus Project Berlin, 1998]

A decision based on emissions reduction

Many policy makers look to NGVs as one of the solutions to urban pollution, based upon how many *tonnes emissions reduced* can be achieved. This can be factored into a cost/benefit analysis and compared to results using alternative

Fig. 3-6
Comparison of external noise: CNG and diesel bus



approaches to reduce pollution. Most NGV users in the average corporate fleets, however, tend to look at the economic benefits and are less concerned about the emissions aspect, although it still is a factor in making a decision.

Supporters of petrol and diesel vehicles make claims that new technologies, coupled with the use of 'clean' petrol and diesel, negate the need for alternative fuels such as natural gas. Consider that:

- The new generation of petrol vehicles are cleaner than ever before. Computer control technologies, new catalysts and low sulphur petrol can compete with some, but not all, light duty bi-fuel NGVs because the NGVs systems have to be balanced to fit different characteristics of two fuels. However, the emissions from a dedicated light duty NGV will be very hard to beat, even for some electric vehicles if the full fuel cycle emissions are taken into consideration.
- The new generation of diesel vehicles—particularly the heavy duty types—are also cleaner than previous generations. Many of these new diesel catalysts and continuously regenerating traps (CRTs), that require low-sulphur fuel.**

* The noise measurement was carried out in accordance with 70/157 EWG of the European Union.

**Emission reduction figures are based upon data taken from the European Auto/Oil II programme and from U.S. Federal Government reports on Alternative Fuels

4. Economy of natural gas vehicle operation

4.1 Cost of diesel, gasoline and natural gas

The differential in the price of natural gas versus the prices of diesel and petrol is the key factor in determining the overall economics of any conversion to NGVs. The other factor is the amount of fuel consumed by the various vehicles that will run on natural gas. Because natural gas generally is cheaper than the other fuels, the more fuel a vehicle consumes, the better the economic payback will be when factoring the NGV project economics. As a general rule of thumb, if the price differential between natural gas and diesel/petrol is about 30% (natural gas being cheaper) then a typical fleet project can payback somewhere in the 3–5 year range, but possibly longer. When the price of diesel/petrol is 50% higher than natural gas, then payback periods fall more into a traditionally acceptable range for investments, in about 2–3 years. But this is a very broad generalisation since there are many factors that must be included in the calculation of each specific project's costs and benefits.

In some countries, natural gas has a clear price advantage against petrol and even diesel due to favourable tax reductions for natural gas. This benefit leads to a drastic shortening of the payback period for the investment in NGVs.

European fuel prices

Fuel prices vary widely, mostly due to taxation. The tax rates on petrol across Europe range from about 64–81%; on diesel about 54–85%; and on natural gas from 0–65% [ENGVA,1996]

- The sale price of the three fuels typically shows that petrol is the highest cost fuel, varying by octane content; diesel is next highest priced and natural gas is the cheapest.
- Private, centrally fuelled fleets that purchase their own fuel in bulk directly from a wholesale company will find their fuel prices lower than the normal pump price at a public fuelling station.
- Public transport companies benefit often from special tax advantages on diesel.
- Prices of diesel fuel may change, however, relative to petrol because some countries are beginning to change their fuel taxation

policies because of suggested linkages between public health and diesel particulates.

Relative fuel prices—specifically tax rates—also are changing in different countries because of government environmental policies that are tending to favour the so-called 'clean' or 'environmental' fuels. For example (at the time of publication) in Switzerland, natural gas costs more than diesel or petrol unless it is from renewable resource biogas, in which case there is no tax on the fuel, making it cheaper than diesel/petrol. In Germany, tax on natural gas has been limited to 15% of the tax on petrol until the year 2009.

Natural gas prices

The price of natural gas as a vehicle fuel will vary widely, even within one country. This is due to a number of factors:

- Different natural gas companies charge different rates for their gas.
- Generally there are very few natural gas companies that have established a 'natural gas vehicle rate' for selling the fuel to the transportation sector.
- Traditionally natural gas companies sell gas on the basis of a 'declining block rate'. That is, the more gas a consumer uses (calculated in 'blocks' of consumption rates) the less the *unit price* will be for the gas. Thus, residential customers tend to pay the highest unit rate and large industrial customers consuming vast quantities pay less per unit of gas supplied.

Many natural gas companies are offering, however, the preferred large customer rates for the natural gas sold as a vehicle fuel in order to be competitive against diesel and petrol and thus provide the best economics for the NGV customers. Also, natural gas companies, unlike diesel and petrol suppliers, often are willing to enter long term contracts (2–5 years) for the fuel. This can lead to improved, more stable gas prices for customers. For large fleets, such as city buses, this can provide a strong economic incentive against diesel prices that tend to fluctuate in different economic conditions.

For the vehicle customer, therefore, it is very important to be in close contact and negotiation with the local gas supplier in order to get the most favourable rate for natural gas relative to diesel and petrol.

4.2 Payback period of natural gas vehicles

Next to the fuel price the investment costs are the crucial factor for the determination of the payback period of NGVs. Today, due to the low number of NGVs produced, NGVs are suffering under a higher sales price than comparable diesel or petrol vehicles. Figure 4-1 gives examples of the additional costs for purchasing NGVs.

The payback period for investment in NGVs is calculated using the additional investment, maintenance and fuel costs.

The fuel costs depend on two factors, the fuel price and the fuel consumption, which results from the efficiency of the engine. For the comparison of the energy consumption of diesel, petrol and natural gas driven vehicles a common base is necessary which for the example below is the heating value of the fuels, expressed in kWh. Figure 4-2 shows the calculation of the payback period for the Fiat Multipla.

As a result, the NGV Multipla reaches the payback after less than 35,000 km. For other cars similar values are achievable, depending on the amount of the additional investment costs, e.g., Honda Civic 53,000 km.

Initial maintenance costs of natural gas vehicles can be expected to be slightly higher than for conventional vehicles due to a "learning curve" effect caused by higher technical efforts for the natural gas engine and the fuel tanks. After the initial period, maintenance costs can be even lower than for conventional vehicles because the use of natural gas results in less wear and tear on cylinders, rings and spark plugs. However, the intervals between oil changes can increase by a factor of two or more and due to the greater weight of the natural gas vehicles a higher tire rub-down can be expected, especially for buses.

For cars and light-duty vehicles, maintenance costs can be estimated to be 5% of the conversion costs (excluding the costs for the storage bottles). For the yearly inspection of the high pressure tanks a lump sum of 50€ can be calculated. [BGW, 1997]

Manufacturer	Vehicle type b = bi-fuel m = monofuel	Additional net costs (Euro)
Original Equipment Manufacturer		
BMW	316 g Compact (b)	3.000
Daimler Chrysler	Sprinter (m), different editions	5.000 - 7.500
FIAT	Marea (b), Multipla (b), Multipla (m)	1.500
Honda	Civic GX (m)	1.750
Iveco	Daily 35.11 GNC(m) Daily 49.11 GNC(m) Heavy duty truck MH 260 E GNC (m)	5.000
MAN	Low-floor articulated bus NG 232 GNC(m) Low-floor articulated bus NG 313 GNC(m) Low-floor standard bus NG 232 GNC(m) Heavy duty truck LT 38 K 06 GNC(m)	40.000 57.500 37.500 37.500
Manufacturer Authorised Conversion		
Ford, GFI Mainz	Ford Ka Ford Fiesta Limousine, 60 1 tank Ford Fiesta Limousine, 80 1 estatanknque Ford Mondeo Turnier Ford Galaxy Ford Fiesta Courier Ford Transit van, 80 1 tank Ford Transit van, 2 x 80 1 tank Ford Transit Pick-up	3.300 3.350 3.400 3.350 3.450 3.050 2.950 3.850 4.500
Volkswagen, IAV Berlin	VW Polo 1.4 VW Polo Variant 1.6 VW Caddy 1.4/1.6 VW Golf IV 1,4/1,6 VW Golf III Variant 1.6 VW Passat, VW Passat Variant 1.6 VW T4/2.0 VW LT II 2.3	4.400 4.450 4.250 4.500 4.300 4.850 4.650 5.700

Fig. 4-1
Additional costs for NG vehicles (list is incomplete)
Stadtwerke Augsburg, 2000

	Multipla natural gas	Multipla petrol super	Multipla diesel
Additional vehicle costs, incl. VAT	1,750 €	–	1,750 €
Fuel price, incl. VAT	0.58 €/kg	0.97 €/l	0.76 €/l
Consumption	5.6 kg/100 km	8.60 l/100 km	7.90 l/100km
Fuel costs	3.25 €/100 km	8.34 €/100 km	6.00 €/100 km
Fuel cost savings • against diesel • against petrol	 2.75 €/100 km 5.09 €/100 km		
Payback • against diesel • against petrol	 0 km 34,381 km		

Fig. 4-2
Determination of the payback period for natural gas vehicles, German example

Vehicle taxes will also affect the pay-back. Some countries reduce taxes for "clean" vehicles, e.g., in Germany, vehicles which conformed to the latest Euro standards were exempt from taxes for a specific period of time. On the other hand, when taxes are based on vehicle weight NGVs are at a financial disadvantage.

In addition, with regard to the national economy the reduced external costs as a result of lower emissions have to be taken into consideration.

5. Guidelines on usage

5.1 Indoor parking

Can a natural gas vehicle be parked safely in an indoor parking garage? What happens if there is a gas leak? Will an explosive situation occur?

Since natural gas is lighter than air, if a leak occurs the gas disperses upwards. The relatively low flammability range of natural gas—5–15% natural gas to air—makes it difficult to ignite when adequate ventilation is available. Ventilation systems have to be integrated into the garage roof to allow dissipating gas to be removed safely.

Two types of garages

While there is a wide range of parking garage designs and different building codes regulating them, they all tend to have two common features: open space for parking and the need for ventilation to mitigate the results of carbon monoxide (CO) released by vehicle exhausts. Two types of ventilation systems are typically used: natural circulation with open building sides and forced circulation for enclosed structures. These features mitigate the effects of natural gas leaks.

A definitive study shows CNG is no problem

A landmark and definitive study on this topic was done in New York City, and was used in a number of major metropolitan areas to help encourage urban regulators to treat NGVs as they do petrol and diesel vehicles. The study, which used sophisticated modelling and empirical testing found:

If a small leak occurs it resulted in no hazard beyond a few centimetres from the leak, and there was no build-up of gas anywhere in the garage. In the worst case, a full discharge (of a natural gas cylinder), did result in a flammable mixture of gas in the garage, but this situation was quickly mitigated by the dispersion of gas into the open space and its removal by the ventilation system. Only a small fraction of the natural gas released was in the flammable region at any one time, and there was no permanent build-up of gas in the garage. Maximum concentrations were reached in a few seconds to a few minutes and declined rapidly thereafter.

A CNG vehicle poses no extraordinary risk in a typical parking garage; that is, the risk of the CNG vehicle is equal to or less than the risk posed by a gasoline fuelled vehicle. This conclusion is valid for both forced and natural circulation type garage designs, and should cover every type of public parking garage normally encountered. Certain unusual situations might not be covered and this includes garages with no ventilation, a garage with no ceiling vents or a garage with a low flow carbon monoxide sensor. Overall, parking in public garages is not a major CNG safety concern." [Ebasco Services Incorporated, 1991]

5.2 CNG vehicle safety in accidents

Vehicles running on natural gas, carrying high pressure cylinders, often are perceived as having greater concerns about the safety in case of an accident. Based on various accident statistics it is clear that vehicles running on compressed natural gas are as safe or safer than vehicles operating on traditional fuels such as gasoline or diesel. [DNV Technical Report, Annex 9, 1992]

Safety regulations for all fuels—liquid or gaseous—will generally ensure that the risk of a fire under normal operating conditions is very small. So it is generally in the event of a crash or equipment failure that a hazardous situation occurs.

A US survey of more than 8,000 vehicles that cumulatively travelled approximately 278 million miles from 1987–1990 found that the injury rate for NGVs per vehicle mile travelled (VMT) was 37% lower than the rate for gasoline-powered fleet vehicles and 34% lower than the entire population of registered gasoline vehicles. In addition to the lower injury rate, no deaths were recorded for the NGVs in the survey. In contrast the deaths associated with the gasoline fleet vehicles surveyed came to 1.28 deaths per 100 million VMT. The US national average was 2.2 deaths per 100 million VMT for all U.S. gasoline vehicles. [IANGV homepage]

There are two fundamental reasons for this excellent NGV safety record: the structural integrity of the NGV fuel system and the physical qualities of natural gas as a fuel.

The fuel storage cylinders used in NGVs are much stronger than gasoline fuel tanks. For example, in the US the design of NGV cylinders are subjected to a number of required "severe abuse" tests, such as heat and pressure extremes, gunfire, collisions and fires.

Thick-walled reinforced aluminium cylinders, steel cylinders or 100% composite materials are used to store compressed natural gas as a vehicle fuel. These cylinders are manufactured and tested in compliance with strict regulations, and have withstood severe abuse testing under conditions far more stringent than gasoline fuel tanks. NGVs submitted to test crashes up to 52 miles per hour, which have been totally destroyed, show little or no damage to the compressed gas cylinders. Bonfire and dynamite tests push cylinders to temperature and pressures exceeding specified limits showing that compressed natural gas cylinders are durable and safe. Further, the fuel system components may be physically protected or located so that the likelihood of damage upon a crash is minimised. Of course, as with all fuel systems, these cylinders are not indestructible and should be inspected periodically to ensure that no surface damage has occurred.

Gas cylinders are equipped with pressure relief devices and shut off valves which automatically shut off the gas supply in the event of tube rupture or when the motor is turned off (e.g., in an accident). To avoid the danger of explosion in a fire, a burst-disc and a melt fuse ensure the controlled release and burning of the pressurised gas before a rupture through overheating may occur [DNV Technical, Annex 10, 1992].

While fuel storage cylinders are stronger than gasoline fuel tanks, the composite material used to encase the tanks are fundamentally more susceptible to physical damage than metals under abusive conditions. For this reason, composite materials on NGV cylinders must be properly handled. After several incidents involving natural gas cylinder ruptures due to some form of chemical attack or physical damage to the composite overwrap on the cylinder, new materials have been developed that reduce the risk of damage and thus increase safety.

When fuel dispensers fail

The experience of Helsinki, Finland

Early one Saturday morning in January 2000, the compressor for HKL Ruskeasuo CNG station broke down. Usually the station serves about 30 CNG buses, 22 of which belong to Helsinki's public transit company, HKL. After some attempts to fix it locally, it became evident that the station would be down for about two weeks, as the broken part had to be taken to Italy to be fixed.

CNG buses have been specified for use in the competitive bidding for particular routes. If the operator is unable to use the bus type specified for the route, it has to pay a penalty. Also, finding temporary replacement buses for 22 buses in a very short space of time is not easy. Thus, the aim was to get the CNG buses running as soon as possible.

To be able to avoid a stop in operations in the event of a CNG station failure at Ruskeasuo, plans were to use the smaller capacity station in Pirkkola (15 buses per day) which would be kept in operating condition for this purpose. However, some oil deposits had been detected in the CNG tanks of the first 11 HKL CNG buses refuelled at the Pirkkola station, so HKL had previously decided that the newer 11 buses should not be refuelled at Pirkkola. Thus, 11 CNG buses had no alternative but to be removed from service until the Ruskeasuo station could be fixed.

To make matters worse, the first attempts to refuel the remaining buses at Pirkkola failed. Suddenly, all 22 buses were out of service due to lack of fuel. After several hours of maintenance and a two-day CNG shortage, on Sunday evening it was finally possible to refuel at the Pirkkola station. To keep at least the 11 older CNG buses running, it was decided to refuel them overnight one after another, since the refuelling round-trip from the depot took about 45 minutes. This meant that one person had to work the night-shift to refuel the 11 buses for two weeks!

The episode finally ended happily when the Ruskeasuo station began to work again after new parts arrived from Italy. As the break-down happened during the warranty period, the repair costs were covered by the station manufacturer. The other costs incurred due to the time and expense of having buses out of service were covered by the CNG station's contractor as stipulated in the station's contract with HKL. Though the story had a happy ending, it does emphasise the importance of being prepared for almost anything, having a back-up system ready and well-maintained, and having a fuel supply contract that does not leave the bus operator in trouble should the fuel supply temporarily be cut off.

Additionally, NGV fuel systems are "sealed," which prevents spills or evaporative losses. Even if a leak occurs in an NGV fuel system, the natural gas dissipates into the atmosphere because it is lighter than air and, unlike liquid fuels does not pool on the ground. Natural gas has also an oderant added so that any leakage can be detected.

Natural gas is not toxic or corrosive and will not contaminate ground water. Natural gas combustion produces no significant aldehydes or other toxins and volatile organic compounds, which are a concern with many fuels.

5.3 Fuelling safety aspects

Natural gas is dispensed into vehicles through sealed systems designed to allow natural gas into the vehicle without any leakage into the atmosphere. In dispensers utilising ANSI-NGV1 nozzles, unless the nozzle is connected to a receptacle on a vehicle, natural gas will not flow.

In case the car drives away with the nozzle still connected, an in-line break-away device positioned in the refuelling hose will disconnect. The flow from the compressor is stopped instantaneously by a check valve and prevents damage to the filling station. Also the check valve on the vehicle will close automatically and stop further flow from the tank [Stäubli, 1998].

6. Support for implementation

6.1 Gas company support

Every gas company approaches the NGV market and its customers slightly differently. Some will be extremely enthusiastic and helpful. Others may not have an NGV marketing programme and be less helpful. If the company is not particularly enthusiastic about the vehicle market, your reception at the gas company when you go looking for assistance may be disappointing. Ask if any of the company's natural gas transmission companies might be able to help. Alternatively, inquire about assistance from a national natural gas or NGV association.

What are you looking for?

When you approach the company, you may be looking for information about:

- vehicles
- refuelling stations
- natural gas prices
- NGV programmes and subsidies available from your local or national government

The gas company should be able to help you 'size' the fleet; that is, determine the size compressor that you will need to fuel your vehicles. This will be determined by a number of factors, including: total fuel storage on board; daily driving distances; fuel consumption; and fuelling patterns, be they once a day or multiple times. Additionally, the gas company also may be able to help determine the best vehicles for conversion, if that is your choice. Or, many of them have contacts with original equipment manufacturers (OEMs) who would be ready to provide information about the availability of NGVs or companies that convert vehicles to NGVs.

6.1.1 Installation of a fuelling station

Every gas company approaches this differently, and there are various financial (and financing) options that are available. Here are some examples of what you might find when discussing the installation of a fuelling station:

- ***Installation on your own property.*** If the fleet is centrally fuelled and you normally take charge of your own fuelling operations (such as in large bus fleets), then installation of a compressor station on your property is most likely.

- ***Creative options*** may also be possible if the gas company is highly motivated in the NGV sector. Some fleets actually allow vehicles of other companies onto their property for fuelling. (You should inquire whether this is possible for your fleet, too) Sometimes it may be possible to install a fuel dispenser outside the perimeter of your company so that other fleets can fuel. In this case, an arrangement with the gas company to install a computer card system would allow the gas company to bill any customers on a monthly basis, if need be.
- ***Public fuelling.*** Some countries are aggressive in building fuelling stations. So the idea of using public stations, as is done for diesel and petrol, is particularly attractive and costs nothing extra to you, the NGV customer.

If you wish to install a fuelling system on your own property, the gas company should be able to assist with codes, safety standards and all aspects of preparing and building the station. Alternatively, they may direct you to any number of private contractors who can help you as well. In this case, the gas company should be able to assist you in developing a bid specification to provide to different contractors to acquire competitive estimates for the work to be performed.

The complexity of installing a fuelling station will vary depending on its size, characteristics of your own site, and whether it is fast fill, slow fill, or both. Access to a natural gas pipeline required and electricity will have to be provided on site as well. Again, the local gas company and/or contractor will be able to assist you.

The type of garage can also affect project implementation and staff costs. In Helsinki, for example, diesel buses have automatic indoor refuelling, while CNG refuelling is outdoors and requires the presence of maintenance personnel. This means that the staff cannot use the refuelling time productively by cleaning the vehicles or checking oil, refilling other fluids etc. as they can with diesel. The gas buses must be first refuelled outside, then driven in for the other manoeuvres, and this takes extra time. In wet and cold climates this may also affect the acceptance of these vehicles by maintenance staff.

6.1.2 Servicing

Either the gas company or one of its local contractors should be available to service your station. Reliability of the station operation is critical in order to keep your vehicles on the road. It will be important to establish up front, with the gas company and/or its service company the terms and conditions of servicing. Everyone must realise that all mechanical devices either break down or need to be serviced. With critical facilities like fuelling stations, it is important that, whatever goes wrong, servicing can be done in a timely fashion. For very large fleets, redundant (backup) systems are critical. Look to the gas companies for such technical support.

6.2 Government support

There are a growing number of programmes in different countries that provide financial and other incentives to NGV customers. This ranges from tax incentives (credits, deductions, etc.) to other financial incentives such as grants for vehicle purchases or fuelling station installation. In some cases, clean fuel vehicles may be allowed to park free in certain locations, or to drive in traffic lanes normally accessible only to taxis and buses. The local gas company representative or the national gas (or NGV) association should be knowledgeable about incentive programmes in your area, and advise you where to go for more information. (Please refer to Section 8 for useful addresses where you can get further information).

7. Available standards

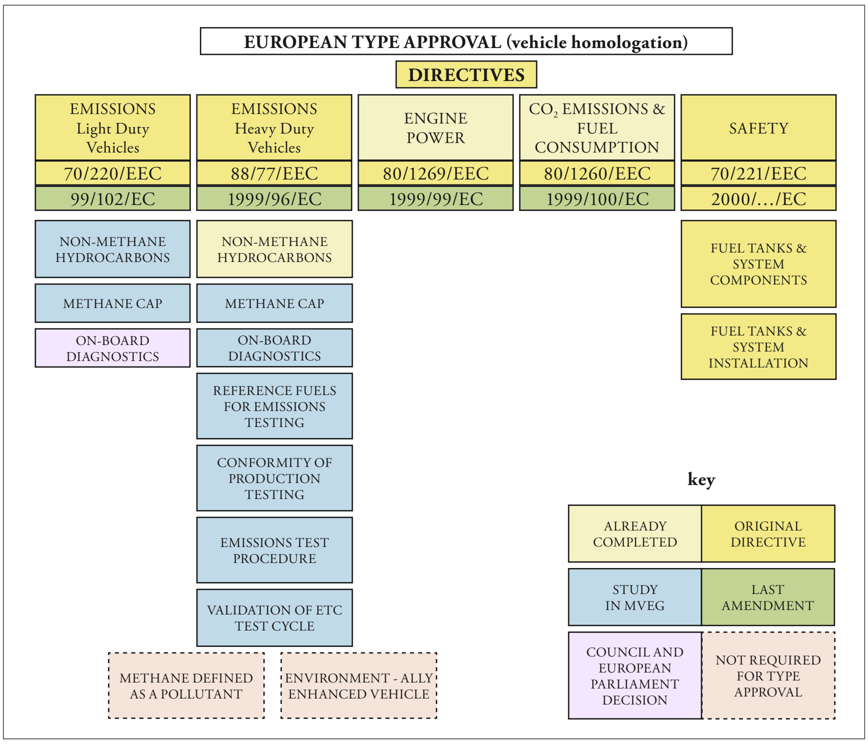
Standards are an important instrument for the systematic development of a new technology. Standards serve the harmonisation of NGV technology at an early stage, facilitate the exchange of goods, increase safety and/or protection of persons, goods and the environment as well as services in Europe and safeguard consumer interests (lower prices, more choice).

A well written standard gives planning security, defines the state-of-the-art and documents the due safety and reliability level.

In order to receive this for the Natural Gas Vehicles Technology standards are developed at European level in co-operation between the European standard institution CEN (Comité Européen de la Normalisation) and ISO, the International Standardisation Organisation.

CEN Technical Committee 326 is the group responsible for developing NGV equipment standards in the European Union. It includes working groups (WG) developing European standards on gas safety requirements for filling station systems and vehicle fuel systems, including NGV conversion systems. WG 1 covers essential safety issues, design and construction requirements as well as the installation of a code of practice for outdoor and indoor refuelling.

Fig. 7-1
European type approval on vehicle homologation



WG 2 deals with safety issues, design and construction requirements for NGV fuel systems from the filling nozzle to the motor conversion system. This includes on-board fuel storage systems such as storage cylinders, pressure relief devices, cylinder valves and the installation code for cylinder mounting.

WG 3 concentrates on operations conditions:

- Customer quality assurance in filling operation, especially safe fuelling condition and optimal filling charge
- Certification of NGV technicians for conversion, diagnosis and repair of NGVs
- Recommended requirements for NGV garages and workshops

For further and regularly up-dated information on NGV standards please refer to the home page of the IANGV: http://www.iangv.org/sources/standards.html.

In addition, the European Commission has developed several directives to regulate European type approval on vehicle homologation (Figure 7-1).

Approved international standards:

- ISO ISO/DIS 11439: High Pressure Cylinder for the On-Board Storage of Natural Gas as a Fuel for Vehicles

International standards in preparation:

- ISO TC22/SC25/WG1: Refuelling Connector (TC Technical Committee, SC Sub committee, WG Working Group)
- ISO TC22/SC25/WG2: Design Principles and Installation of Vehicle Fuel Systems
- ISO TC22/SC25/WG3: NGV Fuel System Components
- ISO TC58/SC3/WG11: Gas Cylinders of Composite Material
- ISO TC58/SC3/WG17: High Pressure Cylinders for On-Board Storage of NG
- ISO TC193: Natural Gas Composition Designa-tion for Use as a Compressed Fuel for Vehicles
- CEN TC23/SC1: High Pressure Cylinders for On-Board Storage of NG
- CEN TC326/WG1: Safety Requirements for Refuelling Stations
- CEN TC326/WG2: NGV Fuel Systems
- CEN TC326/WG3: Safety in Natural Gas Filling Operations

8. Sources of information

Clean Fuels Foundation

The Clean Fuels Foundation is the world's first, and only charitable, public membership-based organisation dedicated solely to the advancement of cleaner-burning alternative transportation fuels produced in America: 1730 K Street, Suite 304, NW Washington D.C., Tel: +1-202-508-3887; Fax: +1-202-337-3759, E-mail: all@cleanfuels.org

Clean Fuels Network

The Clean Fuels Network combines information on energy industry news, weather, stock quotes and pricing data on its website. Links to an expanding number of online industry publications, as well as to the websites of a large and growing number of energy industry participants are provided. Future content and features will target the end-use customer, and enable industry participants to conduct electronic commerce with those customers who are drawn to the web-based energy communities. Website: http://www.naturalgas. com

European Committee for Standardization (CEN)

CEN's mission is to promote voluntary technical harmonisation in Europe in conjunction with world-wide bodies and its partners in Europe. Harmonisation diminishes trade barriers, promotes safety, allows interoperability of products, systems and services and promotes common technical understanding. Wherever possible CEN works with other European bodies and the International Organization for Standardization (ISO). Website: http://www.cenorm.be

Erdgas Mobil

Home page organised by the BGW, Bundesverband der deutschen Gas- und Wasserwirtschaft e.V., Germany. The BGW is the representative of the German gas utilities, water works and sewage treatment plants for political, economic, economic-technical and legal questions. The addresses of the filling stations in Germany are available on the following website: http://www.erdgasmobil.de, E-mail: info@ erdgas-fahrzeuge.de

European Automobile Manufacturers Association (ACEA)

Established in 1991, ACEA is the professional body defending and representing the interests of 13 members of the European automotive industry before the EU and other international institutions. Rue du Noyer 211, B-1000 Brussels, Tel.: +32-2-7325550, Fax: +32-2-7387310, Website: http://www.acea.be

European Natural Gas Vehicle Association (ENGVA)

The European Natural Gas Vehicle Association (ENGVA) is a non-profit organisation whose mission is to develop a sustainable and profitable market for natural gas vehicles (NGVs) throughout Europe by creating a favourable political and economic environment that encourages the development of NGV technology as well as European fuelling infrastructure for natural gas. Spaklerweg 28, NL-1096 BA Amsterdam, Tel.: +31-20-5973100, Fax: +31-20-5973000, E-mail: info@engva.org, Website: http://www.engva.org

FordonsGas

The home page of FordonsGas provides information on the location of natural gas filling stations in Sweden: http://www.fordonsgas.se

The Gas Research Institute

GRI manages a comprehensive research, development and commercialisation (RD&C) programme for the natural gas industry. GRI's mission is to deliver high-value technology, information, and technical services to gas and related energy markets. Website: http://www.gri.org

International Association for Natural Gas Vehicles (IANGV)

The Association was established in 1986 to provide the NGV industry with an international forum and an advocate for NGVs. It now has 200 corporate and individual members in 35 countries. IANGV provides information to members and non-members. Website: http://www.iangv.org.nz

International Gas Union (IGU)

The IGU supports the development and promotes the dissemination of gas technology which will further improve efficiency and the relative (to other fuels) improvement of the environment. The IGU encourages policies in support of natural gas vehicles, which offer a promising solution to combat air pollution by urban traffic: Office of the Secretary General, c/o N V Nederlandse Gasunie, P.O. Box 19, NL-9700 MA Groningen, The Netherlands, Tel.: +31-50-5212999, Fax: +31-50-5255951, E-mail: Secr.IGU@Gasunie.nl, Website: http://www.igu.org

International Organization for Standardization (ISO)

The International Organization for Standardization (ISO) is a world-wide federation of national standards bodies from some 130 countries. The mission of ISO is to promote the development of standardisation and related activities in the world with a view to facilitating the international exchange of goods and services, and to developing co-operation in the spheres of intellectual, scientific, technological and economic activity. ISO's work results in international agreements which are published as International Standards. 1, rue de Varembé, Case postale 56, CH-1211 Genève 20, Switzerland, Tel.: + 41-22-7490111, Fax: + 41-22-7333430, E-mail: central@iso.ch, Website: http://www.iso.ch

International Union of Public Transport (UITP)

Founded in 1885, UITP is a global association of urban and regional passenger transport operators, their authorities and suppliers with over 2,000 members from nearly 80 countries, UITP seeks to promote a better understanding of the potential of public transport. E-mail: administration@uitp.com, Website: http://www.uitp.com

Natural Gas Vehicle Coalition

The NGVC is a national organisation dedicated to the co-operative development of a growing, sustainable and profitable natural gas vehicle market. The NGVC represents more than 200 natural gas companies, engine, vehicle and equipment manufacturers, and service providers, as well as environmental groups and government organisations interested in the promotion and use of natural gas as a transportation fuel. 1515 Wilson Boulevard, Arlington, VA 22209, USA, Tel: +1-703-5273022; Fax: +1-703-5273025, Website: http://www.ngvc.org

SNAM

SNAM is the Eni Group company concerned with supply, transportation and long-distance distribution of natural gas in Italy. The addresses of the filling stations in Italy are available on the following website: http://www.snamretegas.it

1998 OEM Alternative Fuel Vehicles

Information on the 1998 Original Equipment Manufacturers Alternative Fuel Vehicles from the United States. Website: http://www.afdc.doe.gov

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